Wildlife and habitat damage assessment from Hurricane Charley: recommendations for recovery of the J. N. “Ding” Darling National Wildlife Refuge Complex

by

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Executive Summary:

• On 13 August 2004, the first of four hurricanes to strike Florida in <6 weeks came ashore near J. N. "Ding" Darling National Wildlife Refuge (JNDDNWR) Complex, Sanibel Island, Florida. The eye of Category 4 Hurricane Charley passed just north of Sanibel Island with maximum sustained winds of 145 mph (123 knots) and a storm surge of 0.3-2.7 m (1-9 ft). Three USGS-BRD scientists (coastal ecologist and research wildlife biologists) and a USFWS wildlife biologist surveyed the storm damage to JNDDNWR Complex on the ground from 20-24 September 2004.

• At the request of United States Fish and Wildlife Service refuge staff, the USGS team concentrated on assessing damage to wetlands and habitat for selected bird populations (especially mangrove forests, Mangrove Cuckoos [*Coccyzus minor*], and Black-whiskered Vireo [*Vireo altiloquus*]), waterbird rookeries (mangrove islands), impoundments (waterbirds and waterfowl), sea grass beds (manatees), and upland hardwood hammocks and ridges (threatened eastern indigo snake [*Drymarchon couperi*]).

• The refuge complex sustained moderate to catastrophic damage to vegetation, especially mangrove forests and waterbird nesting or roosting islands. Lumpkin Island, Hemp Island, and Bird Key waterbird nesting areas had >50% and sometimes 90% of their vegetation severely damaged (dead, broken tree stems, and tipped trees). The Shell Mound Trail area of JNDDNWR sustained catastrophic damage to its old growth mangrove forests. Direct storm mortality and injury to manatees in the area of the JNDDNWR Complex was probably slight. Manatees may have several strategies to reduce storm mortality, such as, moving along the coast line away from the storm, resting on the bottom of a deep channel and rising only when needed to breathe, and/or hunkering down in a protected inlet or cove. Damage to seagrass beds, an important habitat for manatees, fishes and invertebrates, is believed to be limited to the breach at North Captiva Island. At this breach, refuge staff documented inundation of beds by sand and scarring by trees dragged by winds.

• Because seagrass beads and manatee habitat extend beyond refuge boundaries (see p. 28), a regional approach with partner agencies to more thoroughly assess storm impacts and monitor recovery of seagrass and manatees is recommended.

• Besides intensive monitoring of waterbirds and their nesting habitat (pre- and post-storm), the survey team recommends that the Mangrove Cuckoo be used as an indicator species for recovery of mangrove forests and also for monitoring songbirds at risk (this songbird is habitat-area sensitive). Black-whiskered Vireo may be another potential indicator species to monitor in mangrove forests. Monitoring for these species can be done by distance sampling on transects or by species presence-absence from point counts.

• Damaged vegetation should be monitored for recovery (permanent or long-term plots), especially where previous study plots have been established and with additional plots in mangrove forests of waterbird nesting islands and freshwater wetlands.

• Potential loss of wetlands (and information for management) may be prevented by water level monitoring (3 permanent stations), locating the positions (GPS-GIS) and maintaining existing water control structures, creating a GIS map of the refuge with accurate vertical data, and monitoring and eradicating invasive plants. Invasive species, including Brazilian pepper (*Schinus terebinthifolius*) and air potato (*Dioscorea bulbifora*), were common in a very limited survey and may become more dominant in areas damaged by the storm. Special attention is needed to eradicate these exotic plants.

• As an important monitoring goal, the survey team recommends that species presence-absence data analysis (with probability of detection) be used to determine changes in animal communities. This could be accomplished possibly with comparison to other storm-damaged and undamaged refuges in the Region. This information may be helpful to refuge managers when storms return in the future.

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INTRODUCTION

Large infrequent disturbances (LIDs), such as hurricanes, fires, floods, tornados, and volcanic eruptions, leave an imprint on the ecosystem and are important ecological events (Turner and Dale 1998). Their ecological importance to the animal and plant community, however, is not well understood, but research and our understanding has increased during the last 25 years (Literature cited and suggested reading). LIDs have a continual lasting effect from multiple events that occur over long time periods. For Florida, Ball et al. (1967) estimated that 160,000 to 320,000 major hurricanes (Category 3-5) have occurred in the last 2 million years. In southern Florida, these storms occur every 20 or more years (Lugo et al. 1976). One of the most recent storms came ashore on 13 August 2004 as Category 4 Hurricane Charley at North Captiva Island and passed over much of the J. N. “Ding” Darling National Wildlife Refuge (JNDDNWR) Complex, Sanibel, FL (Caloosahatchee National Wildlife Refuge [NWR], Island Bay NWR, Matlacha Pass NWR, and Pine Island NWR). Within five weeks, a team of scientists was assembled to conduct field assessments of damage and literature searches for assisting the refuge staff with recovery. Our objectives for this research were to conduct an assessment of Hurricane Charley damage to wetlands and habitat for selected bird populations (especially mangrove forests, Mangrove Cuckoos, and Black-whiskered Vireo), waterbird rookeries (mangrove islands), impoundments (waterbirds and waterfowl), sea grass beds (manatees), and upland hardwood hammocks and ridges (threatened eastern indigo snake [*Drymarchon couperi*]). We also contacted potential collaborators and partners for information and possible cooperation for research on the effects of the storm.

Numerous reports exist concerning hurricane damage to tropical coastal ecosystems such as mangrove forests (Reimann 1940, Craighead and Gilbert 1962, Stoddard 1969, Roth 1992, Smith et al. 1994, Doyle et al. 1995, Cahoon et al. 2003), rain forests [*Biotropica*, Volumes 23(4a) and

28(4a)], freshwater swamp forests (Rybczyk et al. 1995), and hardwood hammocks (Horvitz et al. 1995, Slater et al. 1995). Hurricane impacts are complex and range from minor damage, such as defoliation, to catastrophic blow-downs of entire stands. Hurricane damage, however, is much more than impacts to vegetation (Cahoon 2003). Elevation within coastal marshes and forests can be changed by erosion (Jackson et al. 1995), sedimentation (Risi et al. 1995), formation of tip-up mounds and pits (Titus 1990), or by post-event subsidence and compaction (Smith et al. 1994, Cahoon 2003, Cahoon et al. 2003). Defoliation of the vegetation causes inputs of fresh, nutrient-rich leaves into coastal waters and flooding alters the sediment salinity and nutrient regime. Both can impact nutrient fluxes and water quality (Blood et al. 1991, Jackson et al. 1995). Disturbance to the forest canopy results in changed vegetation structure including shorter stature and smaller diameter stems. Importantly, species composition is altered, which may provide conditions for undesirable species to appear or increase in abundance. Vine and liana populations may increase rapidly following the loss of canopy trees (Allen et al. 1997, Sanchez and Islebe 1999, Schnitzer et al. 2000). This period of succession can also include invasions by exotic species (Horvitz et al. 1995, 1998). Tip up mounds and pits created when a tree topples serve as sites for colonization and regeneration for both native and exotic species (Titus 1990, Cooper-Ellis et al. 1999). Often, differences in storm effects are found in close proximity, depending on topography, elevations, and extent of the storm (Walker 1991, Scatena et al. 1996). Hurricane Charley produced a wide variety of damage, short-term, and long-term effects at the JNDDNWR Complex.

Refuge mission and objectives

JNDDNWR Complex joins in partnership with residents of Sanibel, Captiva Islands, Lee County, and the State of Florida to safeguard and enhance subtropical habitat for wildlife. The Complex protects and provides habitat for endangered and threatened species including the west

Indian manatee (*Trichechus manatus*), wood stork (*Myteria americana*), bald eagle (*Haliaeetus leucocephalus*), and eastern indigo snake (*Drymarchon couperi*) as well as other United States Trust Species, such as Mangrove Cuckoos (*Coccyzus minor)* and Nearctic-Neotropical migratory birds. The refuge's staff implements management techniques to sustain natural ecosystem processes and to provide feeding, nesting, and resting habitat for shorebirds, waterbirds, waterfowl, and Nearctic-Neotropical migratory songbirds. The staff also provides high quality interpretive and environmental education programs and recreation compatible to the purpose of the refuge (United States Fish and Wildlife Service 2004).

STUDY AREA

JNDDNWR, the most recent of the refuges in the Complex, was established in 1945 in honor of Jay Norwood "Ding" Darling, a renowned editorial cartoonist, tireless conservationist leader of the early 20th Century, and head of the Biological Survey. The refuge covers 2,571 ha (6,354 acres) of estuarine, open water, sea grass bed, mud flat, impoundment, mangrove, mangrove island, hardwood hammock, and ridge habitats at latitude 26° 27' N and longitude 82° 07' W. The Complex (Fig. 1 and 2) includes four additional satellite refuges: Matlacha Pass NWR (Fig. 1 and 3, 207 ha or 512 acres; 26° 40' N, 82° 05'W), Pine Island NWR (Fig. 1 and 4, 221 ha or 548 acres; 26° 37 N, 82° 10'W), Island Bay NWR (Fig. 1, 8 ha or 20 acres; 26° 48'N, 82° 10'W), and Caloosahatchee NWR (Fig. 1, 16 ha or 40 acres; 26° 42', 82° 48'W). Approximately 44% (1,068 ha or 2,640 acres) of the Complex is designated as Wilderness Area (Fig 5). More than 238 bird, 51 herpetofauna, and 32 mammal species have been identified using refuge habitat (United States Fish and Wildlife Service 2004).

JNDDNWR occupies the north central portion of Sanibel Island, Lee County, Florida (Fig. 1 and 2). Europeans populated Sanibel Island in the 19th century with small fishing settlements and only two persons registered in the 1870 U. S. Census (Hammond 1970). The island reportedly provided ample food in the form of wildlife and fisheries for its residents during that century, including a large feral hog population as early as 1831. Currently, most of the island's private lands (ca. 60% of island) are developed with single- and multiple-level housing and low-density commercial establishments.

At JNDDNWR, refuge personnel manage two impoundments for migratory shorebirds and waterfowl. They conduct regular monitoring of hydrological and water quality conditions in these impoundments. Staff gages have been installed and surveyed to sea level. Water level is recorded twice a month in each impoundment. Additionally, each impoundment is drawn down twice a year, once in the spring and once in the fall. They are, however, not drawn down simultaneously. The East Impoundment is lowered in March and then again in September. The West Impoundment is lowered in April and then in October. During the draw-downs, water quality is monitored in the impoundment being drawn-down and in the adjacent estuary. This is accomplished by deploying two water quality datasondes simultaneously (one in the impoundment and one in the estuary). The sondes record conductivity, temperature, pH and dissolved oxygen. Each data sonde deployment lasts 24 hours and deployments are made for draw-downs of both impoundments.

Of the four satellite refuges, three − Pine Island, Matlacha Pass, and Island Bay – were established to protect nesting waterbirds during Theodore Roosevelt's administration in 1908. Caloosahatchee NWR was established later in 1920. All of the satellite refuges provide islands of mangrove habitat, which are inhabited by a wide variety and large number of colonial nesting waterbirds. Other important habitats on the refuge islands include uplands, sand beaches, and mudflats as well as other wetland habitats. The islands also provide important waterbird resting areas adjacent to foraging habitat in the nonbreeding season.

Geomorphology and Hydrology of Sanibel Island

Sanibel Island is comprised of classical dune ridge and swale topography (Missimer 1973, Stapor et al. 1991). These formations are clearly evident on recent aerial photographs of the island (see the right panels of Figs. 29 and 31. The hydrology of large barriers islands, such as Sanibel, is complex (Anderson et al. 2000). Only larger barrier islands, like Sanibel, have freshwater marshes in dune swales (Rheinhardt and Faser 2001).

METHODS

Hurricane Charley storm development and physical characteristics.

Descriptions of Hurricane Charley's development, storm path, and physical characteristics were drawn from reports and preliminary data primarily published on the internet. Many reputable sources of information, such as NOAA's National Hurricane Center (NHC), made preliminary data and analyses available as soon as possible to the public for research and information purposes. Analyses and reports presented here should be viewed as preliminary and subject to change as agencies and institutions finalize and publish their research after the hurricane season. Electronic copies of the information from web sites or unpublished reports are available from C. A. Langtimm.

Habitat damage and bird surveys

We conducted field surveys of selected major habitats of JNDDNWR and the islands of Matlachee Pass and Pine Island NWR's (Fig. 3 and 4, 2 largest of the satellite refuges) from 20 to 24

September 2004. The islands surveyed provide habitat for large numbers of nesting waterbirds from late February to July each year, but also provide resting habitat within close proximity to foraging sites during other times of the year. At each island or habitat, we collected data on trees using standard techniques for describing hurricane damage (see "Vegetation" below) (Walker 1991, Smith et al. 1994). We collected a GPS position (UTM and LAT-LONG coordinates, NAD83) of the survey and photographed habitat at 2 to 6 recorded bearings (ca. 45 to 180° intervals). We also took an overstory photograph for estimating cover at the same point. These photographs not only provide information on damage, but will allow estimation of damage over a much larger area using visual and other photogrammetric comparisons (i.e., locations can be found on aerial photographs with GPS data). Birds were noted and photographed when encountered; we counted endangered Wood Storks and nesting ibises and herons. Presence of exotic plants was also recorded and the plants were photographed. We sampled and photographed a total of 35 locations in 15 habitats or islands, totaling 168 photographs with GPS in UTM (NAD83) coordinates and bearings in degrees (Table 1). Islands were sampled on the fringe and also at an interior location. Bird nomenclature follows the American Ornithologists' Union (1998).

Manatees

We used several sources of data to document and describe important manatee habitat areas in and near the refuge complex prior to landfall of Hurricane Charley. General descriptions of manatee distribution patterns in the refuge complex were drawn from regional data, analyses, and figures provided by the Fish and Wildlife Research Institute (FWRI) of the Florida Fish and Wildlife Conservation Commission (Sara McDonald, personal communication). Aerial survey data were collected by FWRI in Lee County during twice monthly surveys in 1994-1995 and 1997-1998. Data were analyzed by applying a variable-shape spatial filter to make a contour map of manatee abundance, as described in Flamm et al. (2001). Warm and cold season distribution and relative abundance maps were developed for Estero Bay, Matlacha Pass (including Tarpon and San Carlos Bays) and Pine Island Sound. Two of these regions, Matlacha Pass and Pine Island Sound encompass the landscape administered by the refuge complex.

Movement of individual manatees in these two regions was also monitored by FWRI with satellite telemetry. Tracking was limited to the cold season. Location data were analyzed and maps developed delineating "manatee corridors" used by animals to travel from one area to another, and "manatee places" indicative of important habitat where individuals spend extended periods of time. Data from 16 animals tracked in Matlacha Pass and 12 animals tracked in Pine Island Sound are presented in this report in figures provided by FWRI.

Information on cold season thermal refuges nearest the refuge complex was provided by Mote Marine Laboratory and FWRI, the partners collaborating with USGS Sirenia Project on the Manatee Individual Photo-identification System (MIPS). This program provides state-wide monitoring of manatees through photo-documentation of known individuals at the major winter aggregation sites.

The distribution of seagrass was drawn from regional monitoring and assessment programs, provided by FWRI and as reported by Dawes et al. (2004). An assessment of the degree of scarring of these beds by boat propellers was based on a technical report published by FMRI (Madley et al. 2004).

Data are few on the direct impact of the hurricane on manatees and manatee habitat. Observations of damage to seagrass beds during aerial surveys by refuge personnel and monitoring by Mote Marine Lab are described. We further identify those areas in the refuge complex with the greatest likelihood of impact by comparing the path of the core of the storm with pre-hurricane distributions of primary habitat and manatee high use areas. We then project possible short-term and long-term impacts to habitat and manatees based on principles of biology and findings from previous research at other locations.

Historical characteristics of the Sanibel regional landscape

After our field surveys, we acquired historical topographic sheets for the Sanibel – Captiva – Pine Island area, which were prepared by the United States Coast and Geodetic Survey from 1857-1867. These sheets are not rectified or geo-referenced at this time. Some features, however, are visible on the 19th Century sheets, when compared with the same areas on recent false color infrared aerial photographs (1999). Specifically, we determined if the rookery islands of interest to refuge staff were present on the historic sheets and we compared other specific areas of interest, such as the Shell Mound Trail area.

Vegetation surveys

We conducted qualitative (visual) and quantitative vegetation surveys in a variety of habitats at 15 areas of JNDDNWR Complex. Mangrove forests comprise the majority of forested habitat on the Complex; therefore, more surveys were conducted in these forests. We surveyed and sampled mangrove forests at Shell Mound Trail, Power Line easement (road), Legion Curve, Givney Key, Upper and Lower Bird Islands, Bird Key, Hemp Island, Lumpkin Island, East and West Impoundments, and along Dixie-Beach Boulevard (see Figs. 3, 4, and 5 for island and study locations). Hardwood hammocks were examined at Shell Mound (Fig. 5), along the Legion Curve (west side of Indigo Trail) and at Hemp Island (Fig 4.). We took numerous photographs and recorded notes at all sites (see CD's for complete set of all photographs). We recorded damage and mortality (by species), size (diameter at breast height [dbh] in cm) and direction of fall in plots of known area at several locations. No stems were permanently tagged for future reference although the locations of the plot were recorded in latitude-longitude (degrees to 5 decimal places) and UTM (NAD83) using GPS. In addition, we surveyed four mangrove forest plots (vegetation) that had been established by the Sanibel-Captiva Conservation Foundation Marine Laboratory (SCCF) prior to the passage of Hurricane Charley (plots 5 and 6, near JNDDNWR's West Impoundment and plots 7 and 8, along Dixie-Beach Boulevard).

We made observations concerning the potential for vegetation communities to recover. This included noting the presence or absence of seedlings and/or sapling-sized individuals at all sites. We examined damaged individuals to see if they were coppicing or stump sprouting (the production of adventitious shoots from the main trunk or stump). Special attention was given to vines and lianas, both native and exotic, as they can respond to disturbance very quickly.

Following our field work at JNDDNWR Complex we conducted literature searches to compile lists of potential invasive exotic species which could become of management concern in the future. Articles, literature, maps, and charts pertinent to our surveys and results, have been included in the Appendix CD (pdf files). Botanical nomenclature follows Nelson (1996) and Wunderlin (1998).

RESULTS

History of Hurricane Charley

Hurricane Charley was the third named tropical storm to develop in the North Atlantic in 2004 and the first of four major hurricanes to impact Florida in less than a six week period. It was the first major hurricane to impact Sanibel Island in more than 40 years. A summary of the history of storm development and its path was provided after the storm by NOAA's National Hurricane

Center (http://www.nhc.noaa.gov/2004charley.shtml; 13 June 2005). Charley originated from a tropical wave, which developed into a tropical depression just east of Barbados on 9 August. It moved quickly west-northwestward across the Caribbean and strengthened to a hurricane on 11 August as it passed south of Jamaica. Then, it turned toward the north-northwest passing over western Cuba with Category 3 winds of 105 knots. It weakened somewhat over the lower Straits of Florida while turning northward to the Dry Tortugas. From there, Charley turned toward the southwest coast of Florida. Contrary to forecasts, just prior to landfall it made a sudden turn to the east and intensified rapidly to a Category 4 storm. The eye of Hurricane Charley made landfall on the southwest coast of Florida near Cayo Costa, Lee County, just north of Captiva Island at approximately 15:45 EDT 13 August (Fig 1). Maximum sustained winds were tentatively estimated at a devastating 130 kt – a Category 4 out of 5 on the Saffir-Simpson scale. The hurricane traversed the Northern Charlotte Harbor, coming ashore again at Port Charlotte. It then traversed the central Florida peninsula, moving off the northeast coast of Florida near Daytona Beach, still with hurricane force winds. After moving into the Atlantic, Charley came ashore again near Cape Romain, South Carolina. The center then moved just offshore and made a third landfall at North Myrtle Beach with winds near 70 kt. Charley remained over land where it weakened and became extratropical. Its remnants finally were absorbed by a frontal zone near southeastern Massachusetts.

Overview of storm's physical characteristics

Hurricane Charley was an intense, compact, swift moving storm. Figure 6 presents wind speeds within the hurricane at landfall from a surface wind field analysis provide by the NOAA Hurricane Research Division of the Atlantic Oceanographic and Meteorological Laboratory (http://www.aoml.noaa.gov/hrd/Storm_pages/charley2004/wind.html, 18 Aug 2004). As can be seen from the graphic, the eye of the hurricane at landfall may only have been 8-10 km wide (5 or 6 miles). Maximum observed surface wind speeds of 123 kt occurred 5 nautical miles SE of the eye; the extent of the most intensive and destructive winds was small. The path of the storm brought the core of the hurricane force winds to bear on North Captiva and Captiva Islands, producing an ocean breach on North Captiva at its narrowest point (Fig. 7). The intense core then proceeded northeast impacting the mangrove islands at the north end of Pine Island NWR in Pine Island Sound and, after crossing over the northern segment of Pine Island, hitting the northern mangrove islands of Matlacha Pass NWR. Charley then moved northeast into Charlotte Harbor and inland across Florida. JNDDNWR on Sanibel Island received less damage than the Captiva Islands as it was further south and east of the eye and core.

Although it produced intense surface winds, only a small storm surge accompanied the storm as it made landfall in the area of the JNDDNWR Complex. Figures 8 and 9 present initial data on the observed storm surge from on-site visits by the Coastal High Water Study Team under the Federal Emergency Management Agency (FEMA). The highest levels occurred seaward along the path of the intense core of the storm – North Captiva and Captiva Islands (Fig. 8). Behind the barrier islands, the storm surge was lower (Fig. 9), but again the highest surge was along the path southeast of the storm's eye – at the shoreline of the north segment of Pine Island. Storm surge heights, however, were relatively modest at 4-9 ft (1.2-2.7 m) at their highest point. Brian Jarvinen, storm surge specialist with the National Hurricane Center, reported that forecasters originally predicted a storm surge of up to 18 feet or 5.5 m (J. Thompson, St. Petersburg Times, 17 August 2004). As the storm approached the coast, however, it intensified from a Category 2 to Category 4 hurricane, increased its forward speed to 25 mph (40 kmph), and the core of the hurricane force winds shrank from 24 to 10 miles (38 to 16 km) across. A lower than expected storm surge resulted due to a small zone of winds capable of producing a storm surge, the fast speed that lessened the build up of water ahead of the storm, and the low tide at the time of landfall.

Birds and their habitats

J. N. "Ding" Darling National Wildlife Refuge

Based on our limited surveys, hurricane damage to habitats in this refuge ranged from moderate to severe and catastrophic (Figs. 10 and 11). Older and taller (~10 m) mangrove forests may have sustained more severe damage than mangroves with less stature. Live oak hammocks sustained moderate damage (mostly broken limbs) with rare occurrences of uprooted or snapped trees (Fig. 12). Impoundment aquatic habitat and sea grass beds in the refuge estuary appeared to have only slight to no damage. Wading birds foraged in fairly large numbers (25-50) in impoundments and estuary sea grass beds at low tide during our field survey on 22 September 2004 (Fig. 13). Based on our surveys, most of the severe to catastrophic damage occurred on the northwestern side of the refuge, especially at Shell Mound Trail and next to the powerline rights-of-way areas, which were closer to the eye of the storm (Table 1).

Matlacha Pass National Wildlife Refuge

Lumpkin Island. Hurricane Charley caused severe to catastrophic damage to vegetation on the island (Fig. 14). Upon entry to the island's interior, we located nests of night herons (*Nycticorox* sp. unknown) and one nestling <14 days old (~35-40 days after eggs were laid, Baicich and Harrison 1997). We also observed juvenile White Ibis (*Eudocimus albus*) ca. 4-5 weeks old (almost fledged), which means eggs were first laid 49-56 days previously or about 8 to15 days before the storm.

Upper Bird Island. This small rookery island sustained moderate damage from Hurricane Charley (Fig. 15). The island contained mangroves and limited upland habitat, covered in dense shrub-scrub habitat with patches of grasses and bare sand. Most of the trees and shrubs had leaves, but the island's edge sustained moderate damage from wind and waves. Birds were not observed roosting on the island.

Givney Key. We found moderate storm damage to vegetation on the island with ca. 50% leaf cover remaining on shrubs and mangroves (Fig. 16). We also observed more than 20 White Ibis nests in low shrubs on the island. Twelve nestlings, estimated at 3-5 weeks old, were observed in the shrubs or on the ground near the nests, which indicates that nests and eggs survived the storm (see Lumpkin Island, above).

Lower Bird Island. Upon close approach to the island we observed moderate damage, mainly loss of leaf cover in sections of the island (Fig. 17). We found moderate damage, i.e., snapped trees and loss of leaf cover upon entering the island (Fig. 18). The interior of the island was covered by water. When we entered this area, we flushed 10-12 Black-crowned Night-Herons (*Nycticorax nyticorax*) from dense mangroves, but we did not find any active nests, such as those found on other islands.

Pine Island National Wildlife Refuge

Bird Key. This active waterbird area in Pine Island Sound sustained catastrophic damage to vegetation and nesting habitat (Fig. 19). Most of the canopy trees snapped or tipped in the storm. Little to no leaf cover remained on shrubs and trees. Waterbirds were using the Key for resting just prior to our survey.

Hemp Island. We found catastrophic damage to vegetation and nesting habitat on this island, similar to the damage found on Bird Key (Figs. 20 and 21). On 24 September 2004, we saw large numbers (100's) of waterbirds resting on island, which is located 6.1 km west of North Captiva Island and 2.4 km from Pine Island in Pine Island Sound. While measuring damage to vegetation, we also recorded 11 Wood Storks leaving the island (Fig. 22).

Manatees

Seagrass beds: manatee habitat

Seagrass beds are important foraging habitat for manatees (Best 1981, Lefebvre 2000, Lefebvre et al. 2001) and cover substantial areas of Pine Island Sound, Matlacha Pass, and San Carlos Bay (Fig. 23), primarily in the shallow depths of the waterways (<1-6 ft [<0.3-2 m] Fig. 24). Most of the islands of Pine Island NWR, Matlacha Pass NWR, and Island Bay NWR are surrounded by or adjacent to seagrass beds. JNDDNWR waters also include significant seagrass beds. As of 1995, large sections of seagrasses in Lee County were rated as degraded with light to severe scarring from propeller cuts of boats operating in the shallow waters (Sargent et al. 1995, Madley et al 2004). Areas of scarred seagrass were scattered throughout the region.

The track of Hurricane Charley took the most destructive forces of the hurricane over North Captiva Island (Fig. 6) and across the northern sections of Pine Island Sound, Matlacha Pass, and into Port Charlotte. The worst damage to seagrass appears to have occurred at the breach on North Captiva. Wind and waves eroded sand into the sound burying the seagrass adjacent to the island (Fig. 25). Dr. Brad Robbins, Mote Marine Laboratory (pers. comm.), visited the area after the hurricane and estimated approximately 1 ha (~2.5 acres) of seagrass was lost due to the breach. Refuge personnel documented additional localized damage. Scarring occurred as wind and waves dragged many dislodged trees from the breach across the seagrass beds scouring the vegetation from the substrate. Sand inundation and scars from tree drags are clearly seen in aerial photos (Fig. 25). This area, however, has been repeatedly eroded by storms and undoubtedly will be again. Prior to the breach at North Captiva Island from Charley, two smaller channels were opened in the same area in 2001 from Tropical Storm Gabrielle (USGS Coastal & Marine Geology Program, Hurricane and

Extreme Storm Impact Studies http://coastal.er.usgs.gov/hurricanes/charley/index.html, 16 Oct 2004).

Manatee population

Examination of aerial survey data from the late 1990s (Fig. 26) shows that during hurricane season the highest concentrations of manatees within the refuge complex occur in Tarpon Bay and around Buck Key in JNDDNWR; near Chino Island in Pine Island NWR; and near Big Island and Fisherman Key (San Carlos Bay), Manatee Bay, Master's Landing, McCardle Island (Matlacha Pass), and Bull Island and Brown Pelican Island (north of Matlacha Bridge) in Matlacha Pass NWR. Low abundances of manatees are seen along the west edge of Pine Island Sound with only a few animals found along the eastern edge. By far the greatest numbers of manatees occur throughout areas of Matlacha Pass and San Carlos Bay. The distribution of manatees (Fig. 13) correlates fairly well with the distribution of seagrass (Fig. 23). The low number of sightings along the east edge of Pine Island Sound is probably a factor of low water levels preventing manatees from easily feeding on the seagrass there (Fig. 24). The area where the breach occurred at North Captiva Island was characterized as a low-use manatee area prior to the hurricane. Within the cold season the distribution patterns are similar with the exception of fewer manatees sighted in Pine Island Sound (Fig. 27). A similar pattern is seen from the telemetry data (Fig. 28).

Vegetation

Historical comparisons

All seven of the islands used by nesting waterbirds that we visited appear on the 19th Century topographic sheets of the region. Although the islands were initially protected because of their nesting birds in the early 1900s, we wanted to be sure that they were not the result of dredging operations. In particular, the Bird Islands (both upper and lower) and the Tarpon Bay Keys, had an appearance of being spoil islands. Examination of the topographic sheets, however, showed that this was not the case. The Tarpon Bay Keys are clearly apparent on Sheet #T-693 (Fig. 29). Bird Key is clearly indicated also on sheet #T-738 (Fig. 30). The other rookery islands also appear on these early maps. This does not mean necessarily that the islands have not changed over time, or that they have not been impacted since the advent of dredging.

Another interesting comparison is that of the Shell Mound Trail – Power Line Road – West Impoundment area of the refuge (Fig. 31). The open water shoreline of the impoundment appears unchanged, yet some other water bodies have clearly changed over time. Additionally, there is evidence of vegetation change with the possible infilling of a coastal marsh by mangrove forest vegetation (Fig. 31). Determining all of the changes from the 1857 charts to present is beyond the scope of this report.

Pre-hurricane island geomorphology, vegetation structure, and hurricane damage

We used the descriptions for mangrove forests first proposed by Lugo and Snedaker (1974) and used by Odum et al. (1982) in their south Florida mangrove forest community profile. The waterbird breeding islands fall into three, broad, categories: overwash forests, fringe forests and basin forests. Several islands have more than one type of mangrove forest present. Tarpon Bay Keys are low in elevation and are inundated at high tide. Therefore, these are overwash islands dominated by red mangrove (*Rhizophora mangle*) trees. Lower Bird Island is relatively small (<1 ha). It has fringe mangrove forests around its perimeter. The interior of this island is a slightly elevated open area, with woody vines (e.g., nicker bean, *Caesalpinia* spp.) and exotics (e.g., Brazilian pepper, *Schinus terebinthifolius*).

The remaining four islands are more complex and have higher elevation areas that lie well above mean high tide. Areas with higher elevations support native and exotic plants. Bird Key, Givney Key, Hemp Island, and Lumpkin Island are fringed by red mangroves, just inland of which lies an elevated berm. These berms have both tropical hardwood species (e.g., gumbo limbo, *Bursera simaruba*) and invasive exotic plants (e.g., Brazilian pepper) growing on them. Interiors of these four islands are typical basin-type mangrove forests (Table 2). The presence of these basin mangroves sets these islands apart from the others. Basin mangroves are poorly drained and thus are often flooded for long periods of time. On these islands, we found fine to course forest soils with shell hash and high organic matter content (T. J. Smith, personal observation). These interior basin forests were dominated by the black mangrove (*Avicennia germinans*), with red mangroves abundant only on Lumpkin Island, while the white mangrove (*Laguncularia racemosa*) was uncommon throughout (Table 2). Hemp Island was further differentiated from the others by the presence of a very high (≈ 20 ft or 6.1 m above msl) mound that formed a partial ring around the western side of the island. This mound was covered in a tropical hardwood hammock dominated by gumbo limbo with an understory of Jamaica dogwood (*Piscidia piscipula*). A large gumbo limbo had been tipped-up revealing that the mound is in fact a shell midden, probably dating to the Calusa culture (Walker et al. 1998). Two exotic plant species, both indicative of white settler habitation, lily and papaya, where also present at this location (Fig. 32).

An interesting feature of Hurricane Charley was that it was fast moving and did not have a large storm surge (Figs. 8 and 9). We found evidence of overwash and sediment deposition on two waterbird islands, Upper Bird Island and Givney Key (Fig. 33). It appeared, however, to be very limited in extent. Overall, there appeared to be little evidence of sediment having been carried into the interior of the islands.

Hurricane damage to vegetation

Vegetation damage ranged from simple salt burns on plant leaves; to loss of leaves and some branches through heavy defoliation, crown damage and some windthrow; to almost complete loss of the forest canopy with high tree mortality (Fig. 34). In general, we observed the most severe damage in mangrove forests and least severe damage in live oak, cabbage palm, and tropical hardwood hammocks. Damage also appeared to be least in the southern portions of the Complex and increased northward towards the location where the eye of Hurricane Charley crossed the coastal barrier islands. Our quantitative data support this view (Table 2). We measured the greatest damage on Bird Key where the basin forest had 60-90% tree mortality. In geomorphologically similar forests on Givney Key, mortality approached only 20% (Table 2). Data from the SCCF mangrove plots (4) also showed these trends (E. Milbrandt, unpublished data).

The area of the Shell Mound Trail – Power Line Road deserves a special comment (Fig. 31). The mangroves in this area appeared to be what Lugo (1997) termed “old growth” forest. This is an unusual and rare form of mangrove forest. The trees are quite large in diameter and height and stem density is low. The crown is dense and there is little or no understory, which means there is no pool of seedling or sapling-sized individuals. Our observations in this area indicated that all of these characteristics were present prior to Hurricane Charley. Unlike the waterbird islands where black mangrove was dominant, the Shell Mound Trail forest was dominated by very large red mangroves

(≈ 30 to 50 cm dbh), with large black and a few white mangroves, scattered throughout. The forest canopy in this area was catastrophically damaged. Mortality of canopy-sized individuals was in the range of 80-100%.

Regeneration following disturbance

Many plants have the ability to regenerate vegetatively following disturbance. This is especially true for plants of tropical origin; however, species differ in this ability. For example, the red mangrove can't coppice or stump sprout (Smith et al. 1994). Black mangroves, however, can (Fig. 35). Tropical species such as gumbo limbo and sea grape also resprout very quickly following disturbance (Fig. 35).

Another factor affecting forest recovery is advance regeneration. This refers to the presence of seedling and sapling-sized individuals in the forest at the time of disturbance. These individuals, which are already present, form the pool from which the new forest canopy develops. We observed advance regeneration at many mangrove forests, but not all (Fig. 36). In particular, the Shell Mound Trail – Power Line Road forest was devoid of advance regeneration.

Hurricane disturbance creates a variety of micro sites within the vegetation for regeneration that had not been present prior to the storm. New light regimes exist and the topography of the forest floor is altered by tip-up mounds and pits. Tip-ups were present in all forests we visited (Fig. 37), but appeared to be most abundant in the basin forests of waterbird nesting islands. Tip-ups are especially important in mangrove forests. Here they provide regeneration sites for species not normally encountered in these forests. We found many tip-ups with non-mangrove species regenerating on them (Fig. 38). Following Hurricane Andrew, tip-up mounds in mangroves were extensively colonized by invasive exotics such as Brazilian pepper, papaya, and lather leaf (T. J. Smith, personal observation, see also Table 3).

Vines, lianas, and disturbance

We encountered vines at every site we visited, including Upper Bird Island, the smallest of the waterbird islands. The most common vine we found was nicker bean, a native species (Fig 39). We also found Virginia creeper, poison ivy, devils claw, grapes, morning glories, and mangrove rubber vine (Table 3). Interestingly, we did not encounter coin vine, which is common in mangrove forests of Everglades National Park. This is most likely a result of limited surveys rather than true absence. Finally, we found a very aggressive, invasive exotic vine, air potato, at two locations, Shell Mound Trail and near Legion Curve (Fig. 39). We learned that another invasive vine, rosary pea, was present on the refuge, although we did not observe it during our visit.

Observations on exotic plants

Numerous exotic plant species were encountered during our surveys (see above and Table 3). The most abundant exotic plant on the waterbird islands was Brazilian pepper. On several islands we found wading bird nests in Brazilian pepper plants (Fig. 40). The most problematic exotic we encountered is the vine, air potato (Fig. 39). This species is extremely aggressive and can spread rapidly. It has the capability to become established along the edge of a wetland and then spreading over the wetland using the native plants for support, like a trellis. Other invasive vines also can do this, particularly lather leaf (Table 3), which is a problem in coastal regions of Everglades National Park.

Freshwater wetlands

We did not survey freshwater wetlands which are present on JNDDNWR (Fig. 41). There may be, however, evidence of human activities that have altered the surface hydrology of the refuge in the past (besides the waterbird impoundments). The Shell Mound Trail – Power Line Road area mangroves appear particularly to have been impacted (see Fig. 5 and 31 for location). We found several water control structures along Power Line Road (Fig. 42). It appears, from our one observation, that freshwater was being impounded to the west of Power Line Road. This high water may be another factor that contributes to the lack of advance regeneration in the mangrove forests from Power Line Road westward to Shell Mound Trail. Mangrove propagules and seedlings cannot become established in standing water; they require tidal dry-downs (Smith 1992).

DISCUSSION

Past history and future probabilities of major hurricanes in the area of Sanibel Island and Port Charlotte

The area in and around JNDDNWR Complex is hit periodically by tropical storms and by minor and major hurricanes (Category 3-5). The landscape has repeatedly been sculpted by wind and waves from tropical cyclones. Prior to Hurricane Charley, three major hurricanes occurred in the area since 1900. The Great Miami Hurricane of 1926 first devastated Miami as a Category 4 storm then passed over San Carlos Bay and Captiva Island as a Category 3 storm. In 1944, an unnamed Category 3 storm passed west of the area making landfall near the Sarasota County line. The last major hurricane to impact the area was in 1960 when Hurricane Donna took a storm track similar to Charley. Donna made landfall as a Category 4 Hurricane near Naples and cut a path north to Ft. Myers and across the peninsula to re-enter the Atlantic Ocean near Daytona Beach. The storm track of the eye of Donna was east of the Complex, but the size of the storm was immense, and the Charlotte harbor area was subjected to hurricane force and greater winds for over four hours (Dunion et al. 2003).

The relative inactivity of hurricane-status storms since Donna has been due to a larger global climate pattern. Hurricane activity in the western Atlantic is known to occur in multi-decade cycles that alternate between active and quiet phases of 25-40 years each (Gray 1990, Landsea 1993). In 1995, we entered a new cycle of increased activity that is expected to continue for the next 20 to 40 years (Landsea et al. 1996). Global warming is not expected to alter this multi-decade cycle, but a recent analysis concludes that it will likely result in hurricanes of higher intensity and precipitation rates than experienced in the past with a greater risk of occurrence of highly destructive Category 5 storms (Knutson and Tuleya 2004).

Habitat damage and effects on bird populations

Hurricanes have direct and indirect effects on birds (Wiley and Wunderle 1993). The storm's direct effect kills birds (Semple 1936, Hooper 1990, Meyers et al. 1993) or displaces them 1,000's of kilometers from their original home ranges (Chapin 1934). Bird mortality in the short-term, caused by indirect effects from storms, can be precipitated by a loss of food supplies, foraging substrates, nesting and roosting sites, or from increases in predation, conflicts with humans, and changes in microclimate (Hooper et al. 1990: Cely 1991; Waide 1991a ,1991b; Wiley and Wunderle 1993; Wunderle 1995). Seed, fruit, and nectar feeding birds may suffer the most, immediately after the hurricane (Askins and Ewert 1991; Waide 1991a, 1991b; Wunderle et al. 1992; Wiley and Wunderle 1993). More than 87% of 1,765 Red-cockaded Woodpecker (*Picoides borealis*) cavity trees were lost in South Carolina during and after Hurricane Hugo (Hooper 1990). Positive impacts on bird populations also occur. Many insectivorous and omnivorous birds increase after hurricanes and may be adapted to storms by the plasticity of their diets and habitat requirements (Waide 1991b), but some investigators suggest that birds move away temporarily (Askins and Ewert 1991). Lost of foraging habitat could cause birds to move elsewhere, especially in winter. Wunderle et al. (1992) found large declines of wintering Black-and-white Warblers (*Minotilta varia*) in Jamaica after Hurricane Gilbert, which was probably related to large losses of tree trunks for foraging. We expect similar effects on birds at JNDDNWR Complex from Hurricane Charley.

Birds may also shift and adapt to storm damage, e.g., by feeding in different habitat (canopy birds feeding in understory, Wunderle [1995]) or by building nests on fallen debris (e.g., Brown Pelicans [*Pelecanus occidentalis*], Pierce 1990) or at new locations nearby (Cely 1991). We expect Brown Pelicans at JNDDNWR Complex to build nests on damaged habitat and successfully rear their young given that fish populations in the area have not been impacted negatively and that spring high tides do not destroy nests. Erosion of pelican nesting islands during Hurricane Hugo and loss of nesting substrate on three islands in South Carolina caused failure of most of the 3,000 nesting pelicans a year after the storm because of lower nesting substrate and a high tide in late May (Marsh and Wilkerson 1991). Increased numbers of nesting pelicans, however, arrived shortly after that destructive high tide event at a nesting area 45 km to the SW, which was unaffected by the Hurricane Hugo storm surge and spring high tides. Pierce (1990) found that Brown Pelicans learned to build nests on damaged habitat or fallen debris and actually increased the number of fledglings the year following Hurricane Hugo. We expect pelicans at JNDDNWR Complex to also successfully maintain their breeding colonies. Site fidelity is strong for this species based on years of experience with construction related habitat changes and continual increases of nesting pairs (2,12, to >300 pairs) in Mobile Bay, Alabama (J. M. Meyers, personal observation and unpublished data).

Only one Bald Eagle nest was reported lost at JNDDNWR Complex (K. Willett, personal communication). Bald Eagles rebuilt 21 of 24 destroyed nests at their original nesting territory after Hurricane Hugo (Cely 1991). We would expect eagles nesting at the complex, which have lost nests, to rebuild within the same area, although the nest may be built in shorter trees or man-made objects.

Bird population declines from storms over the long-term may be caused by loss of habitat, but habitat usually recovers with plant succession. Forest interior birds may be absent for 1-2 years in former forest habitat after a storm (e.g., 17 mo after Hurricane Joan in Nicaragua, Wiley and Wunderle 1993). The bird community changes in this situation, to one associated with edge and second growth (shrub-scrub) habitat until forest structure develops. An exception to this type of recovery would be severe to catastrophic hurricane damage to old growth forests where recovery may take from decades to a century (Hooper 1990, Wiley and Wunderle 1993). Some bird populations may decline in old growth mangrove and oak hammock habitats of JNDDNWR Complex, especially those habitats with severe to catastrophic impacts from the storm, e.g., major losses of tree canopy from tree snaps and tips. Monitoring species richness and abundance will provide valuable information on recovery from the hurricane as well as benefiting the refuge's mission and management goals. Methods that account for differences in species detection probabilities will provide better estimates of population and community changes (Buckland et al. 1993; Nichols and Conroy 1996; Boulinier et al. 1998, Nichols et al. 1998a, 1998b; Hines et al. 1999). Residents, such as the Mangrove Cuckoo, and migrants, such the Black-whiskered Vireo or other high priority Nearctic- Neotropical migrants (see Rich et al. 2004) should be the focus of monitoring. Monitoring for these species can be done by distance sampling on transects or by species presence-absence from point counts.

Waterbird breeding colonies in slightly damaged nesting habitat from Hurricane Hugo, showed quite different results in breeding after the storm passed over Pumpkinseed Island, South

Carolina (Sheppard et al. 1991). White Ibis (*Eudocimus albus*) breeding pairs in one colony declined from 10,000 pairs to zero after the storm. Although ibises were in the area, they failed to initiate breeding and may have moved south. There was, however, evidence that freshwater wetlands used by feeding ibises were modified by saltwater intrusion caused by a high storm surge. Nesting White Ibis in the JNDDNWR Complex will probably continue nesting there if freshwater feeding areas were not inundated by saltwater. We expect that a minimum of damage occurred to freshwater feeding areas because of a relatively low storm surge from Hurricane Charley.

Nesting Great Egrets (*Ardea alba*) and Tricolored Herons (*Egretta tricolor*) declined at Pumpkinseed Island colonies affected by Hurricane Hugo. Nesting Great Egrets declined 44% because of nesting habitat loss (marsh elder, *Iva frutescens*). This species also did not change its average nesting height after the storm. On Pumpkinseed Island, Great Egrets showed site fidelity by nesting on damaged habitat, but some may have moved 7 km south. This will probably also occur at JNDDNWR Complex in 2005 with some waterbird colonies nesting on damaged habitat, at lower heights, or even on the ground while other colonies may shift to new nesting areas, if available nearby. Nesting on the ground will probably increase mortality from high spring tidal overwash, which caused an 86% abandonment rate of Snowy Egret (*Egretta thula*) nests after Hurricane Hugo in South Carolina (Shepherd et al. 1991). About 80-90% of all Snowy Egrets nested on the ground a year after Hurricane Hugo with few nests surviving overwashes that year. Pierce (1990, 1991) reported loss of breeding for one year at Red-footed Booby (*Sula sula*) colonies in the Virgin Islands after Hurricane Hugo; however, Sooty Tern (*Sterna fuscata*) colonies increased in breeding pairs in the same area. Saliva (1989) also reported loss of waterbird nesting habitat (loss of rocks or vegetation) and nesting waterbirds on the Culebra Islands, Puerto Rico, but also noted that Hurricane Hugo created more tern nesting habitat (sandy areas).

Wunderle et al. (1992) found increases in Mangrove Cuckoos four months after Hurricane Gilbert, but a limited sample size (n = 0 pre-storm, n = 3 post-storm) and increases in detection rates makes this increase doubtful. Overall, Wunderle et al. (1992) found that total bird abundance increased in mangrove forest four months after Hurricane Gilbert, but this also could be a result of increased detection rates for birds after the storm. Mangrove Cuckoos are common in Florida and Caribbean coastal mangroves and oak hammocks (e.g., 4.7 Mangrove Cuckoos/km on transects in Puerto Rico, Kepler and Kepler 1978) and would be an ideal species to monitor post-Charley at JNDDNWR, especially if pre-storm data exist. The species also has lost 60% of its habitat in south Florida to land cleared for residential and agricultural uses (Hughes 1997). Cuckoos forage on lepidopterans, *Anolis* (become compressed or more dense in lower vegetation after hurricanes) and orthopterans, which should all increase post-Charley based on previous hurricane research (Reagan 1991, Waide 1991a, Torres 1992, Hughes 1997). Mangrove Cuckoos, however, may be absent from forest fragments of <12.8 ha (Bancroft et al. 1995).

Another songbird, the Black-whiskered Vireo, may also be an excellent indicator species of mangrove forest habitat conditions at JNDDNWR. This vireo inhabits coastal mangroves and hardwood forests in southern Florida, and specializes in mangroves in Florida (Chace et al. 2002). Black-whiskered Vireos are foliage gleaners of insects or fruit found high in trees (Cruz 1980b, 1987), which makes them ideal for assessing recovery of old growth mangrove forests. The species is also highly susceptible to parasitism (>50%, Chace et al. 2002) from a recent invader, the Shiny Cowbird (*Molothrus bonariensis*), a species that will probably increase after the storm and should also be monitored.

Some bird populations increase with changes in habitat caused by storms (e.g., species of shrubs, grasslands, and wetlands; Wiley and Wunderle 1993). Arengo and Baldessarre (1999) believed that hurricanes may benefit Greater Flamingos (*Phoenicopterus ruber*) in wetland habitats of the Yucatán Peninsula, Mexico, by changing salinity, food quality, density, and availability, i.e., water depth. By monitoring species presence and absence from sites, managers could track changes in bird communities, bird species extinctions and additions, and turnover rates on the refuge (Nichols and Conroy 1996; Boulinier et al. 1998, Nichols et al. 1998a, 1998b).

Seagrass beds: manatee habitat

Research suggests that intact seagrass beds are generally resistant to the physical forces of extreme storms (Tilmant et al. 1994, Whitfield et al. 2002). Furthermore storms are thought to improve seagrass meadows by removing detritus and necrotic tissue, resulting in healthy growth after the storm (Whitfield et al. 2002). Significant localized damage, however, can occur from sediment deposition after hurricane-induced erosion, as occurred at the Captiva breach and in Mississippi Sound after Hurricane Camille (Eleuterius and Miller 1976); or from wave action on patchy, fragmented beds destabilized by propeller scars, motor vessel groundings, or natural blowouts. Past research has shown that scarring can be enlarged and recovery of scars slowed or reversed under hurricane forces (Whitfield et al. 2002). The USGS assessment team could not evaluate the hurricane's impact to seagrass in the entire refuge complex. Given the degree of propeller scars reported for the region in 1995 (Sargent et al. 1995) and 2004 (Madley 2004), it is possible more localized damage occurred in those areas with scarring. The new scars by tree drags may have further destabilized the area near the breach making it vulnerable to new storms.

The USGS assessment team recommends that refuge staff examine the post-hurricane aerial photographs for any large injuries to the seagrass beds within the refuge complex boundaries. If an on-site visit to these sites shows major instability, it may warrant management action. Whitfield et al. (2002) and Kenworthy et al. (2002) offer management approaches to stabilize degraded areas. Such action should speed recovery and prevent further injury. Continual monitoring for vessel groundings and major scarring, with options to remedy such injuries when they occur, should be considered for inclusion in the Refuge Management Plan. But as every manager knows, prevention is always preferred over remediation.

With seagrass beds extending beyond refuge boundaries, the group also recommends a regional approach to damage assessment and future monitoring and research. The refuge complex has an excellent partnership with the Sanibel–Captiva Conservation Foundation and its Marine Laboratory. Two studies on seagrass integrity and ecological function are part of their core research program (Bortone et al. 2004) and include monitoring within the JNDDNWR Complex. A larger regional collaboration with the South Florida Water Management District and the Florida Department of Environmental Protection is part of these studies and offers possibilities to develop a larger partnership. The refuge, foundation, and its partners may want to consider expanding monitoring to sites beyond Sanibel and Captiva islands and into Pine Island and Matlacha Pass NWRs, perhaps in conjunction with monitoring on some of the mangrove island bird rookeries.

Manatee population

The Florida manatee is listed as endangered under both federal and state law. Concerns regarding Hurricane Charley's impact on manatees focus on three issues: (1) direct mortality, (2) permanent emigration of individuals out of the area as a result of the storm, and (3) the loss or degradation of seagrass beds, an important food source for manatees.

Mortality and emigration concerns are based on analysis of extreme storms that struck the Florida panhandle and north Gulf Coast in the 1980s and 1990s. Mark-recapture statistical analysis of manatee photo-identification data (Langtimm and Beck 2003) identified lower adult survival rates for manatees of the region during three years with storms rated Category 3 or higher on the Saffir-Simpson hurricane scale: 1985 with Hurricanes Elena and Kate, 1993 with the March "Storm of the Century," and 1995 with Hurricane Opal. Data suggest that extreme storms have a significant effect on adult survival rates; however, the apparent drop in survival also might be explained, at least in part, by emigration from the region.

Loss or degradation of seagrasses can result in lower manatee reproduction rates as well as a lower number of individuals that the habitat can support. Seagrass beds degraded by propeller are of special concern because they are more vulnerable to hurricane forces (Whitfield et al. 2002) and slower to recover than intact seagrass beds (Kenworthy et al. 2002).

Little is known about what cues manatees use to discern the approach of a major storm or what strategies they use to protect themselves. Given the manatee is a tropical species, one would expect that they have developed behaviors to deal with tropical storms. Several strategies could be employed: move along the coast line away from the storm, rest on the bottom of a deep channel and rise only when needed to breathe, and/or hunker down in a protected inlet or cove. The effectiveness of these behaviors and the vulnerability of manatees to storm forces should depend on (1) the destructiveness of a hurricane, which varies by physical factors such as wind intensity, speed and duration of the storm, storm surge, occurrence of battering waves; (2) physical features of the coastline that can offer protection (barrier islands, protected coves), and (3) coincidental factors such as the density of manatees in the strike area, the number of storms within a season, and occurrence with other health or mortality risks.

Hurricane Charley produced hurricane force winds throughout the JNDDNWR Complex, with the most intense winds crossing North Captiva and northern Pine Island. However, with the exception of the area north of the Matlacha Bridge, relatively few high-use manatee areas experienced the strongest winds. Although Charley was a Category 4 storm when it hit, its potential destruction was reduced by the compact size, short duration, and the lack of a significant storm surge. The outer barrier islands of Sanibel, Captiva, and North Captiva and the inner barrier Pine and Little Pine Islands should have provided some physical protection along with the deeper channels in the pass and sound (Fig. 24). The relatively fast speed of the storm eliminated the development of two additional forces that also could be dangerous to manatees – storm surge and battering waves. All of these factors suggest that the manatee population in the refuge area did not experience a major direct impact from Hurricane Charley. Given the seagrass in the area did not sustain heavy damage it is likely the magnitude of impact to the southwest manatee subpopulation was minimal.

Several studies are already underway to monitor and assess the impact to manatees. These should not require resources from the refuge. USGS Sirenia Project, FWRI, and Mote Marine Laboratory are collaborating under the direction of Dr. Catherine Langtimm to incorporate analysis of effects of the 2004 hurricanes into their long-term study to estimate manatee population parameters using photo-identification data. Estimates of adult survival will require at least two years of data from the winter aggregation sites, but an assessment for impact signatures in the data will be completed after the end of one year. Annual monitoring by Mote Marine Laboratory at Matlacha Isles and the Ft. Myers Power Plant will continue and should provide information on resightings of known individuals and whether a percentage of animals are missing from their usual winter refuge or have been documented at another refuge. Mote Marine Laboratory under the direction of Dr. John Reynolds continues to conduct aerial surveys in Lee County and will be comparing post-hurricane distributions to those from previous years. FWRI continues to monitor manatee carcass recovery, and under the direction of Dr. Holly Edwards will again conduct a winter synoptic survey of manatees at the aggregation sites in the region. All of these data will be analyzed by researchers at their respective institution and reviewed by the Manatee Population Status Working Group under the auspices of the Florida Manatee Recovery and Implementation Team as indicators of possible effects to the population. USGS will be happy to forward information and reports as they become available, put Refuge personnel in touch with key researchers, and provide continued technical support regarding manatee issues.

Other trust species

The refuge staff has observed eastern indigo snakes at drift fence surveys from 2003-2005 (K. Willet, personal communication). If a population exists on Sanibel Island, we expect that little or no mortality occurred because of Hurricane Charley. The opening of forest canopy by the storm should provide more suitable habitat and potentially more prey for this threatened snake (J. M. Meyers, personal observation from ongoing telemetry study in Georgia).

Vegetation

We recommend that permanent plots for monitoring vegetation recovery or mortality be established in the refuge's mangrove forests. We believe that monitoring vegetation in a rigorous, quantitative manner with appropriate quality assurance and control may benefit wildlife habitat management. In this regard, the refuge is fortunate to have a partner in the Sanibel–Captiva Conservation Foundation, and its marine laboratory. Professional staff at the lab have established a network of 24 vegetation plots in the mangroves of the JNDDNWR Complex, or nearby sites. Three plots were established at each of eight locations, with four locations representing impounded mangroves and four locations being non-impounded mangrove forest. Data derived from these plots are already proving useful. We recommend some improvements for the plots for long-term monitoring. At present the plots are not permanent. A center stake is needed and individual stems should be tagged, and mapped (Fig. 43). Stem mapping (Fig 44) and the use of permanent, individually numbered, aluminum tree tags will greatly reduce the possibility of error during subsequent surveys of the plots, allow for measuring growth, recruitment, and delayed mortality. Mapping is valuable if another storm occurs; you only need to find a single, tagged stem to reconstruct the entire plot based on geometry. Finally, we recommend that these plots be established also in waterbird islands and the Shell Mound Trail mangrove forests.

New establishments of vegetation plots could be two additional plots to each waterbird island, where possible, especially Bird Key, Hemp Island, and Givney Key. An alternate method may be required on the smaller fringe and overwash islands. New plots in non-mangrove vegetation, such as the tropical hammock at Shell Mound Trail and Legion Curve areas would also be beneficial. Because of the more complex nature of the vegetation structure in these areas, particularly higher species richness, larger plot sizes will be needed. Once established, the plots need to be sampled annually for approximately five years and then they can be split into two groups with each group sampled every other year.

The survey team visited only a small portion of the JNDDNWR Complex, yet we observed a variety of invasive exotics. Conducting surveys for this group of plants requires different methods than for monitoring recovery. The only effective method is repeated, 100% coverage, followed by treatment to eradicate the pest plants. Seedlings of some exotic plants existed in the mangrove forests prior to Hurricane Charley, but were suppressed by the intact forest canopy. Loss of the mangrove canopy may allow these seedlings to begin vigorous growth. Furthermore, tip-up mounds will provide a different type of habitat for both native and exotic plants to colonize.

We provide, here, some recommendations for determining sediment elevation in mangrove forests in relation to recovery of the forests. In may not seem to be logical, or feasible, but sampling sediment elevation is necessary. We know that large scale disturbance can result in sediment collapse in mangroves and retard, or even, prevent recovery (Cahoon et al. 2003). We recommend a study to look at sediment elevation changes in the heavily damaged mangroves. At least two sites should be examined, one on a large waterbird island (Lumpkin, Hemp, Givney) and the other in the Shell Mound Trail – Power Line Road area. The idea would be to test potential management actions that could be taken to prevent, slow, or ameliorate elevation loss. Such actions might include planting mangrove propagules, especially the red mangrove, with and without fertilization. An additional factor to examine is wetland water elevation. The experiment would be designed to give an answer as to which course of action (above) is feasible for refuge managers.

Ecosystem function and refuge management

Disturbances, especially large infrequent disturbances (LIDs), affect ecosystem function in south Florida and the Caribbean basin. Ecosystems there have developed and are maintained by the periodic severe hurricanes (LIDs) on approximately 20-25 year intervals or more. Although ecologists have recognized the importance of LIDs in maintaining ecosystems (Turner and Dale 1998), there is still much to learn (Tanner et al. 1991). In the Caribbean basin, hurricanes are the major LID that organizes natural systems (Walker et al. 1991).

Major ecosystem structural changes occur with hurricanes. One of the most important factors that result from hurricanes is control of species composition (Walker et al. 1991). Plant growth and recolonization occurs rapidly after storms, but predicting effects of storms is difficult because of the heterogeneity of storm damage within relatively small areas and differences between storms (Brokaw and Grear 1991, Brokaw and Walker 1991, Walker 1991). Hurricanes also affect some aspects of ecosystem dynamics, such as processes caused from increased nutrients from large amounts of litter fall (Tanner et al. 1991). All of these hurricane effects will take place on JNDDNWR Complex to some extent, depending on the location and severity of the storm in that area.

Storm effects on animals, after the initial direct mortality (which is usually low), are highly correlated to changes in habitat structure and function. Increase in solar radiation in damaged forests stimulates plant growth, depending on the seed bank, which in turn creates habitat and food for animals (J. Meyers, personal observations). JNDDNWR Complex will experience these changes, which are similar to what has occurred after other storms in the Caribbean basin (Brokaw and Grear 1991; Brokaw and Walker 1991; Tanner et al. 1991; Waide 1991a, 1991b; Walker 1991; Pimm and Davis 1994; Smith et al. 1994; Doyle et al. 1995; Scatena et al. 1996; and others in *Biotropica* Special Issue 28[4a]). Most vegetation at JNDDNWR Complex will recover rapidly. Exceptions may be old growth mangrove forests, which will recover slowly or not at all (see mangrove section). Insects, probably least disturbed by storms of all animal classes, will increase in species and numbers (outbreaks, Waide 1991b). Butterflies (associated with new growth, see Torres 1992), frogs (Woolbright 1991, 1996), lizards (Reagan 1991), and freshwater shrimp (Covich et al. 1996) increased after Hurricane Hugo. These increases, if they occur on JNDDNWR Complex, may affect populations of trust species, such as the threatened indigo snake and migratory birds. A modified/improved design and analysis for sampling trust species post-storm, e.g., presence/absence especially for birds, would be beneficial for long-term management and may also provide information on hurricane effects for management on other refuges in areas affected/unaffected by the hurricanes of 2004 (Nichols and Conroy 1996; Boulinier et al. 1998, Nichols et al. 1998a, 1998b). A regional approach using this type of design and analysis for all refuges (damaged and undamaged by hurricanes in coastal Florida and Alabama in 2004) may provide valuable information on the effects of the storms and potential management strategies for many priority, endangered, and trust species.

RECOMMENDATIONS

Birds, other trust species, and their habitats

(1) Continue to monitor waterbird breeding colonies and extend surveys to additional islands to document losses or movement of colonies. Take special note of damaged structure and how waterbirds use the structures for nesting. Note nest losses caused by storm overwash in areas where tree or shrub nesting waterbirds nested on the ground. Publish recovery results related to storm and renesting in state or regional journal.

(2) Develop an ecological indicator for monitoring mangrove habitat recovery using the Mangrove Cuckoo and Black-whiskered Vireo. Use survey methods that account for detection probabilities (distance sampling or double-observer) on transects or point counts.

(3) Continue to monitor endangered species (e. g., eastern indigo snake, manatee, and Bald Eagle). Publish results of Bald Eagle renesting if it occurs in local or state bird journal.

(4) Continue to monitor sea grass beds for damage (losses after storm in previously damaged area, e.g., propeller damaged areas) and recovery.

(5) Continue cooperative manatee surveys with other agencies and provide information for regional approach to potential impact of major storms on manatee survival within three years post-storm.

(6) Develop a regional approach to monitoring effects of hurricanes on refuges using a species presence-absence method (Nichols and Conroy 1996; Boulinier et al. 1998, Nichols et al. 1998a, 1998b) (e.g., presence-absence, would be beneficial for long-term management and may also provide information on hurricane effects for management on other refuges in areas affected/unaffected during 2004-2005).

Vegetation

(1) Develop an understanding of what the pre-development watershed was like. What was connected where and how did the surface water flow? This is necessary so that managers can accurately judge what has changed. Some of this information is, or will soon be, available based on historic nautical charts (see Fig. 31). Other parts will need to be developed based on new data (see below).

(2) An accurate topographic map of the JNDDNWR should be developed and entered in to the refuges GIS database. The "standard" USGS 7.5 minute Digital Ortho-photo Quarter Quadrangles (DOQQ) do not have the necessary vertical detail. A survey using small footprint airborne LIDAR (LIght Detection And Ranging) could yield the necessary information. This information would be valuable for more than just hydrology, it could aid in vegetation and wildlife work.

(3) All water control structures and culverts on refuge roads should be located, mapped, measured for their size and elevation above mean sea level, and checked to see if they are functional. The data can be spatially referenced and put in GIS.

(4) Three permanent stations should be established to monitor surface water level and conductivity on the refuge. One station should be placed in each impoundment and one in the bay, possibly near the junction of the dike that separates the two. Hypsometric curves need to be developed so that stage levels can be converted to flooding frequencies in the wetlands in the impoundments. Enough data need to be gathered to enable refuge staff to be certain, that when a water control board is set to a given height, they know how much of an impoundment is flooded. The impoundments are more than the open water area, they are wetlands also.

(5) Water levels should also be monitored in the interior freshwater wetlands of the refuge. This could be accomplished with staff gauges (and regular visits by staff) or by carefully choosing one or two sites for more permanent stations.

(6) Continue to monitor and eradicate exotic plants, especially in hurricane damaged areas.

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Table 1. Refuge, habitat, and locations for hurricane damage assessment using photographs (canopy and terrestrial), bearings, and GPS, 21-24 September 2004, J. N. "Ding" Darling National Wildlife Refuge (NWR) Complex, Sanibel, Florida.

Refuge	Habitat	Location name
J. N. "Ding" Darling NWR	mangrove	MG-05
J. N. "Ding" Darling NWR	mangrove	GP 5
J. N. "Ding" Darling NWR	mangrove	unknown
J. N. "Ding" Darling NWR	mangrove	MG-06
J. N. "Ding" Darling NWR	mangrove	Shell Mound
J. N. "Ding" Darling NWR	oak hammock	Legion Curve
J. N. "Ding" Darling NWR	mangrove and field	Power Line Road
J. N. "Ding" Darling NWR	mangrove	MG-07, Dixie-Beach Boulevard
Matlacha Pass NWR	mangrove island	Lumpkin Island
Matlacha Pass NWR	mangrove island	Upper Bird Island
Matlacha Pass NWR	hammock - scrub	Upper Bird Island
Matlacha Pass NWR	mangrove island	Givney Key
Matlacha Pass NWR	mangrove island	Lower Bird Island
Pine Island NWR	mangrove island	Bird Key
Pine Island NWR	mangrove island	Bird Key
Pine Island NWR	mangrove island	Hemp Island

Table 2. General characteristics of seven waterbird islands visited by the survey team, 21-24 September 2004, "Ding" Darling National Wildlife Refuge Complex. NM = Not measured; Other = tropical hardwood species.

Islands	Geomorphic Type	Tree Density (number/ha)				Tree Mortality
		Black mangrove	Red mangrove	White mangrove	Other	
Tarpon Bay Keys	Overwash islands	NM	NM	NM	NM	None apparent based on visual inspection
Lower Bird Island	Fringe	NM	NM	NM	NM	0 - 10%
Givney Key	Fringe and basin	1200	200	0	0	0 - 17%
Upper Bird Island	Fringe and overwash	1000-1600	0-200	0-600	0	0 - 25%
Lumpkin Island	Fringe and basin	600-800	1200-1400	0	0	50 - 71%
Hemp Island	Fringe and basin	NM	NM	NM	900	50 - 75%
Bird Key	Fringe and basin	400-900	100-200	0	0	60 - 90%

Table 3. A partial list of plant species observed 21-24 September 2004 or occur based on previous knowledge, “Ding” Darling National Wildlife Refuge Complex, Florica. Also listed in the exotics category are species that may become of concern to management in the future (see Horvitz et al. 1995, 1998).

Common Name	Scientific Name	Observed	Growth habit
NATIVE			
Leather fern	*Acrostichum aureum*	Yes	Fern
Black mangrove	*Avicennia germinans*	Yes	Tree
Red mangrove	*Rhizophora mangle*	Yes	Tree
White mangrove	*Laguncularia racemosa*	Yes	Tree
Buttonwood	*Conocarpus erectus*	Yes	Tree
Gumbo limbo	*Bursera simaruba*	Yes	Tree
Jamaica dogwood	*Piscidia piscipula*	Yes	Tree
Live oak	*Querus virginiana*	Yes	Tree
Sea grape	*Coccoloba uvifera*	Yes	Tree
Coral bean	*Erythrina herbacea*	Yes	Shrub / Tree
Cabbage palm	*Sabal palmetto*	Yes	Palm
Cats claw	*Pithecellobium unguis-cati*	Yes	Shrub
Necklace pod	*Sophora tomentosa*	Yes	Shrub / Tree
Seaside mahoe	*Thespesia populnea*	Yes	Shrub / Tree
Christmas berry	*Lycium carolinianum*	Yes	Shrub
Coin vine	*Dalbergia ecastophyllum*	No	Vine
Mangrove rubber vine	*Rhabdadenia biflora*	Yes	Vine
Nicker bean	*Caesalpinia spp.*	Yes	Vine
Milkweed vine	*Mikania scandens*	Yes	Vine
Milkwithe	*Sarcostemma clausem*	Yes	Vine
Marine vine	*Cissus trifoliata*	No	Vine
Virginina creeper	*Parthenocissus quinqefolia*	Yes	Vine
Poison ivy	*Rhus toxicodendron*	Yes	Vine
Devil's claws	*Pisonia aculeata*	Yes	Vine
Grapes	*Vitis spp.*	Yes	Vine
Morning glories	*Ipomoea spp.*	Yes	Vine
Snowberry	*Chiococca alba*	No	Vine
EXOTIC			
Brazillian pepper	*Schinus terebinthifolius*	Yes	Shrub / Tree
Papaya	*Carica papya*	Yes	Tree
Rosary pea	*Abrus precatorius*	Yes	Vine
Air potato	*Dioscorea bulbifora*	Yes	Vine
Lather leaf	*Colubrina asiatica*	No	Vine

Gold coast jasmine	*Jasminum dichotomum*	No	Vine
Brazilian jasmine	*Jasminum fluminense*	No	Vine
Mysore raspberry	*Rubus albescens*	No	Vine
Pothos	*Epipremnum pinnatum*	No	Vine
Caleurpa	*Cauleurpa taxifolia*	No	Marine alga

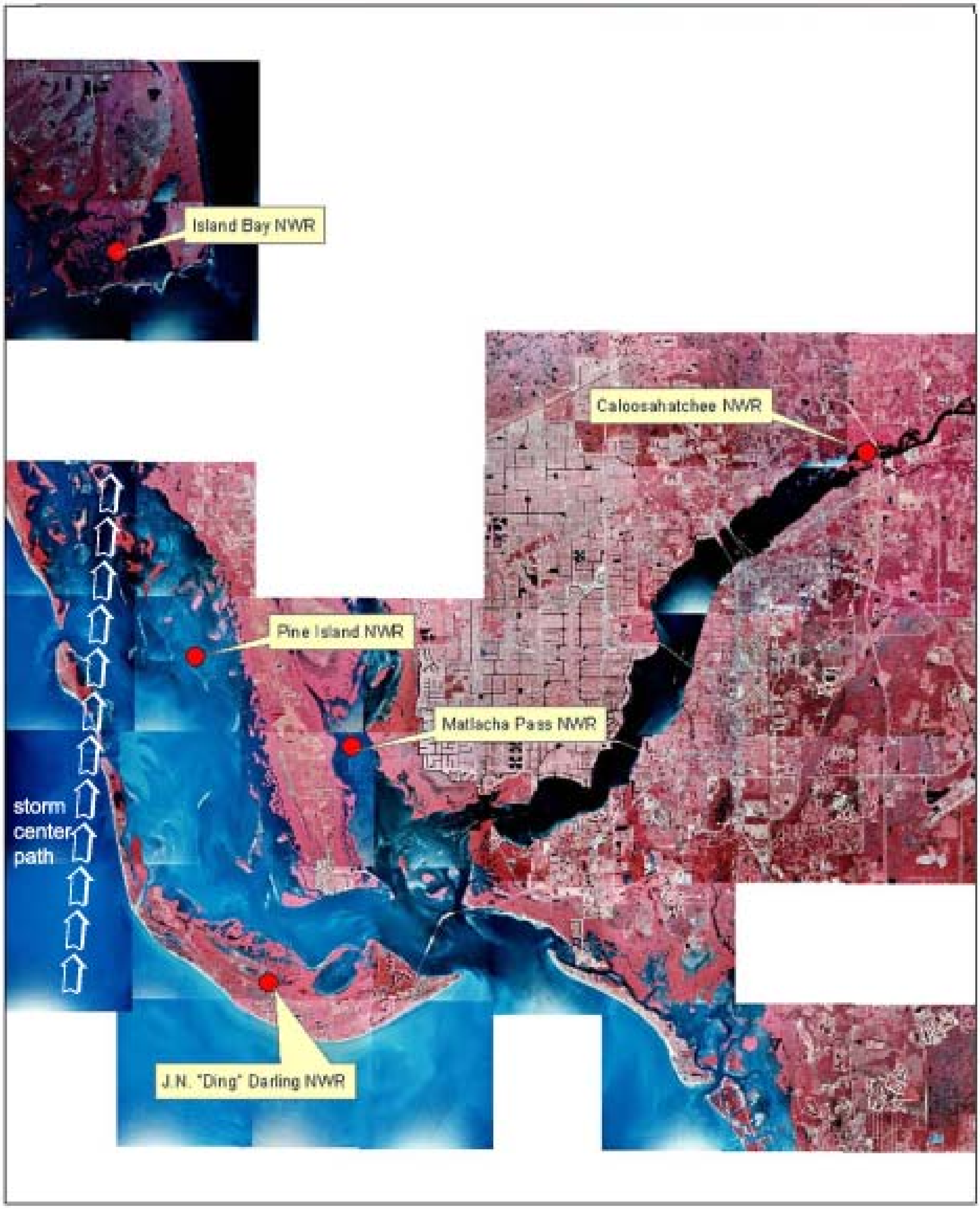

Figure 1. J. N. "Ding" Darling National Wildlife Refuge Refuge Complex, Charlotte and Lee Counties, Florida.

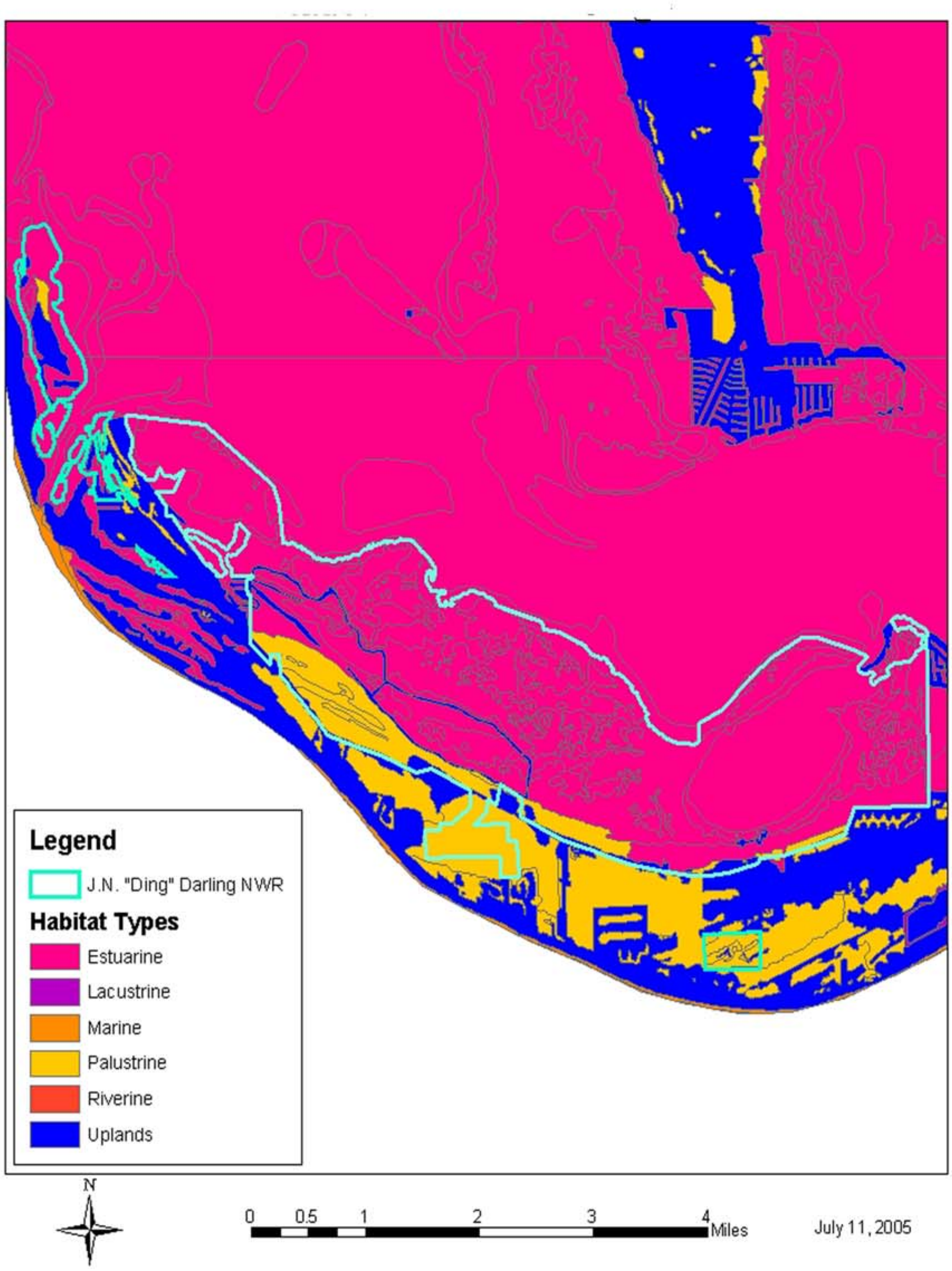

Figure 2. Habitat types of J. N. "Ding" Darling National Wildlife Refuge, Florida, July, 2005.

Figure 3. Islands surveyed on Matlacha Pass National Wildlife Refuge, Florida, 20 to 24 September 2004.

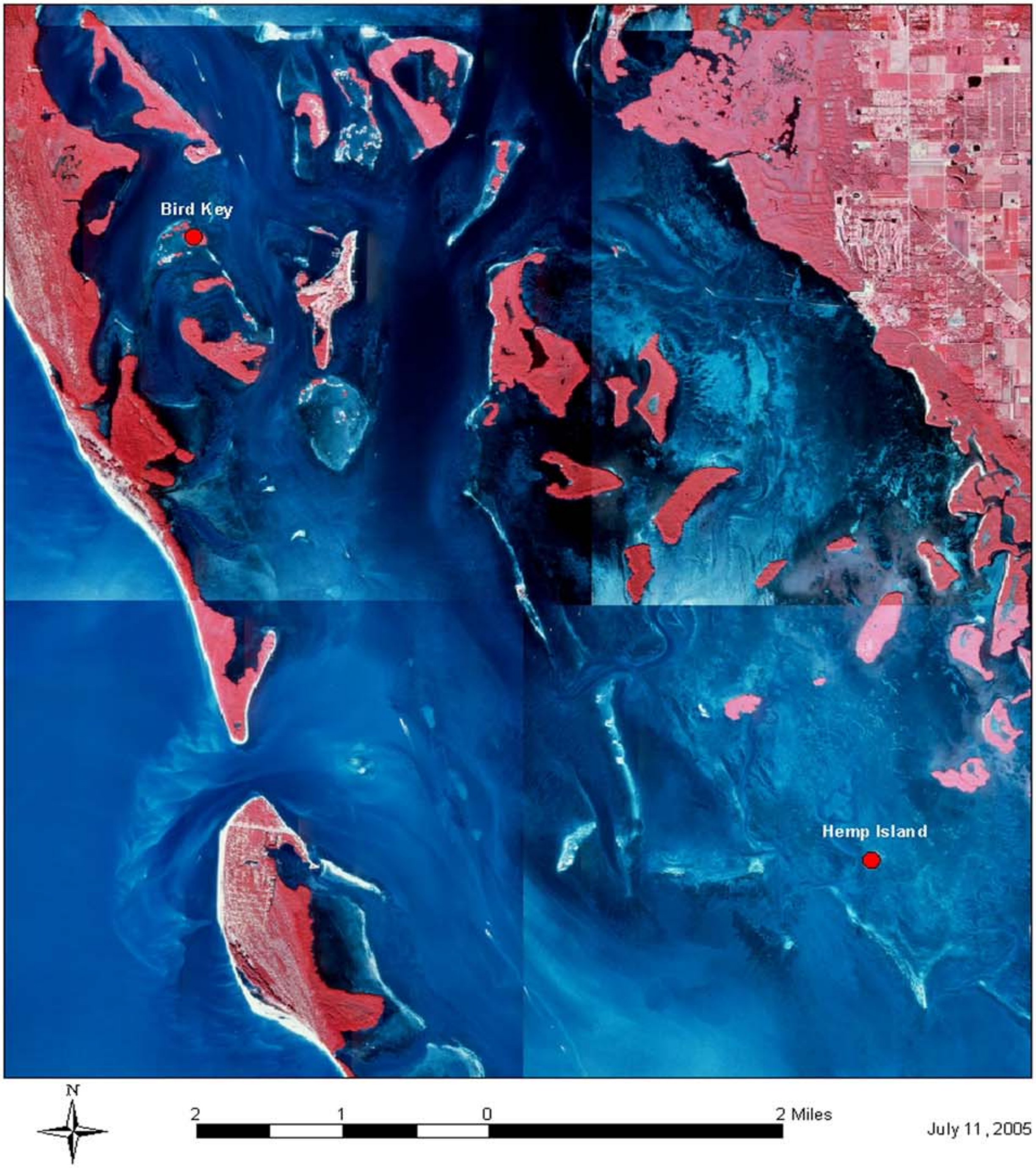

Figure 4. Islands surveyed on Pine Island National Wildlife Refuge, Florida, 20 to 24 September 2004.

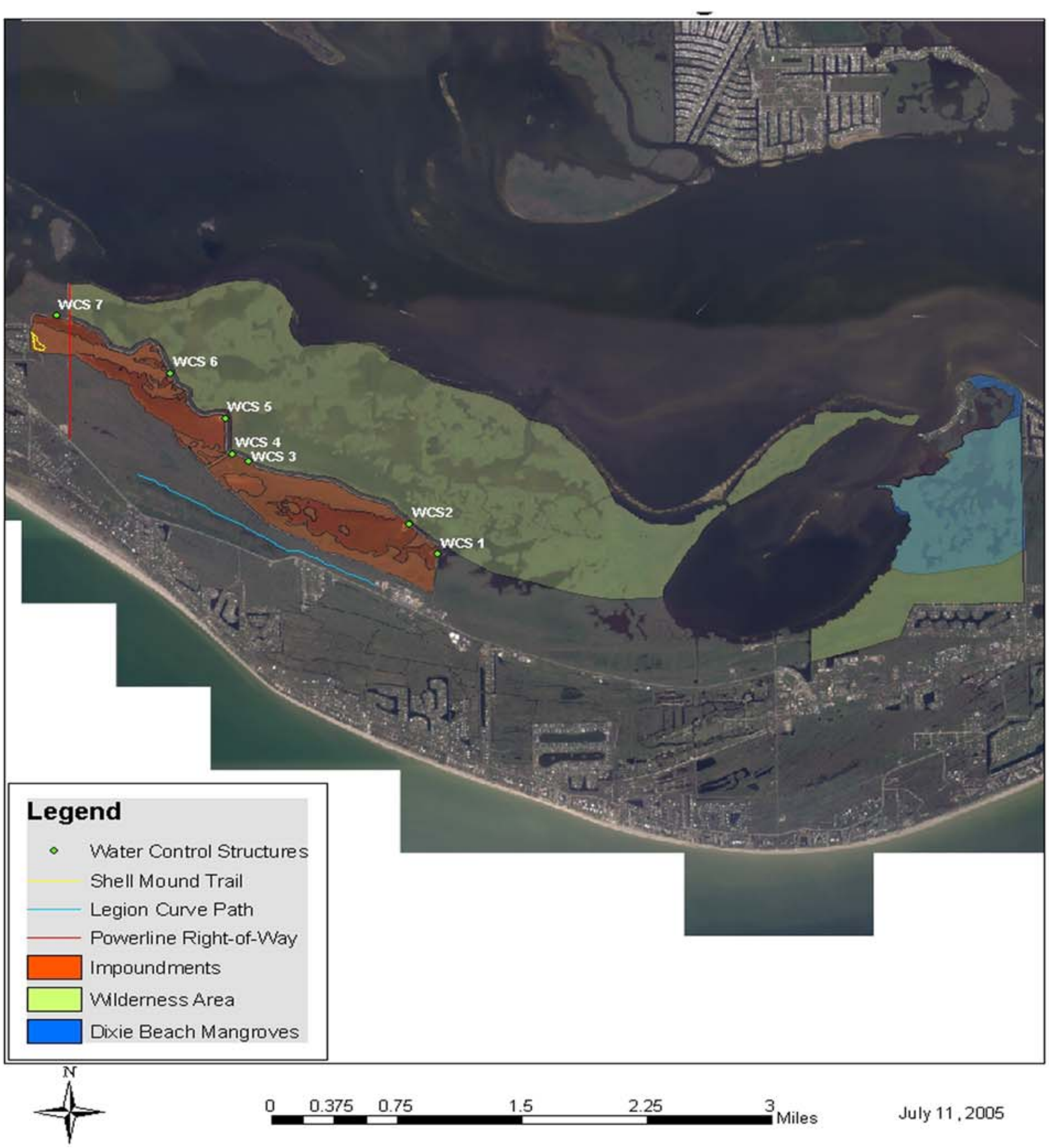

Figure 5. Locations of study sites for Hurricane Charley damage assessment, J. N. "Ding" Darling National Wildlife Refuge, Florida, 20-24 September 2005.

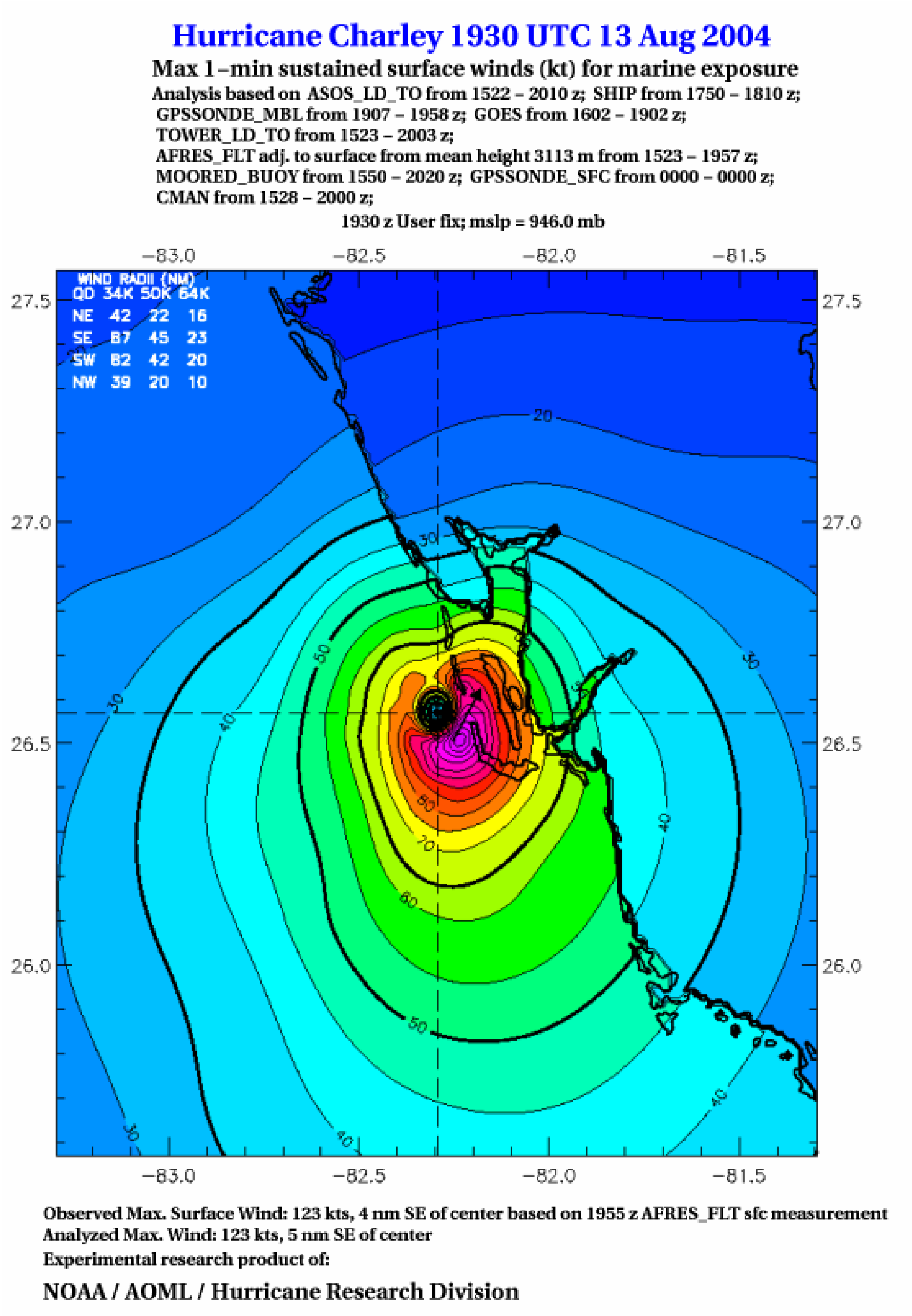

Figure 6. Depiction of the surface wind field of Hurricane Charley just prior to landfall near Ding Darling National Wildlife Refuge. Analysis and graphic provided by NOAA's Hurricane Research Division of the Atlantic Oceanographic and Meteorological Laboratory (http://www.aoml.noaa.gov/hrd/Storm_pages/charley2004/wind.html). The eye of the hurricane is west of the arrow depicting the forward motion of the storm.

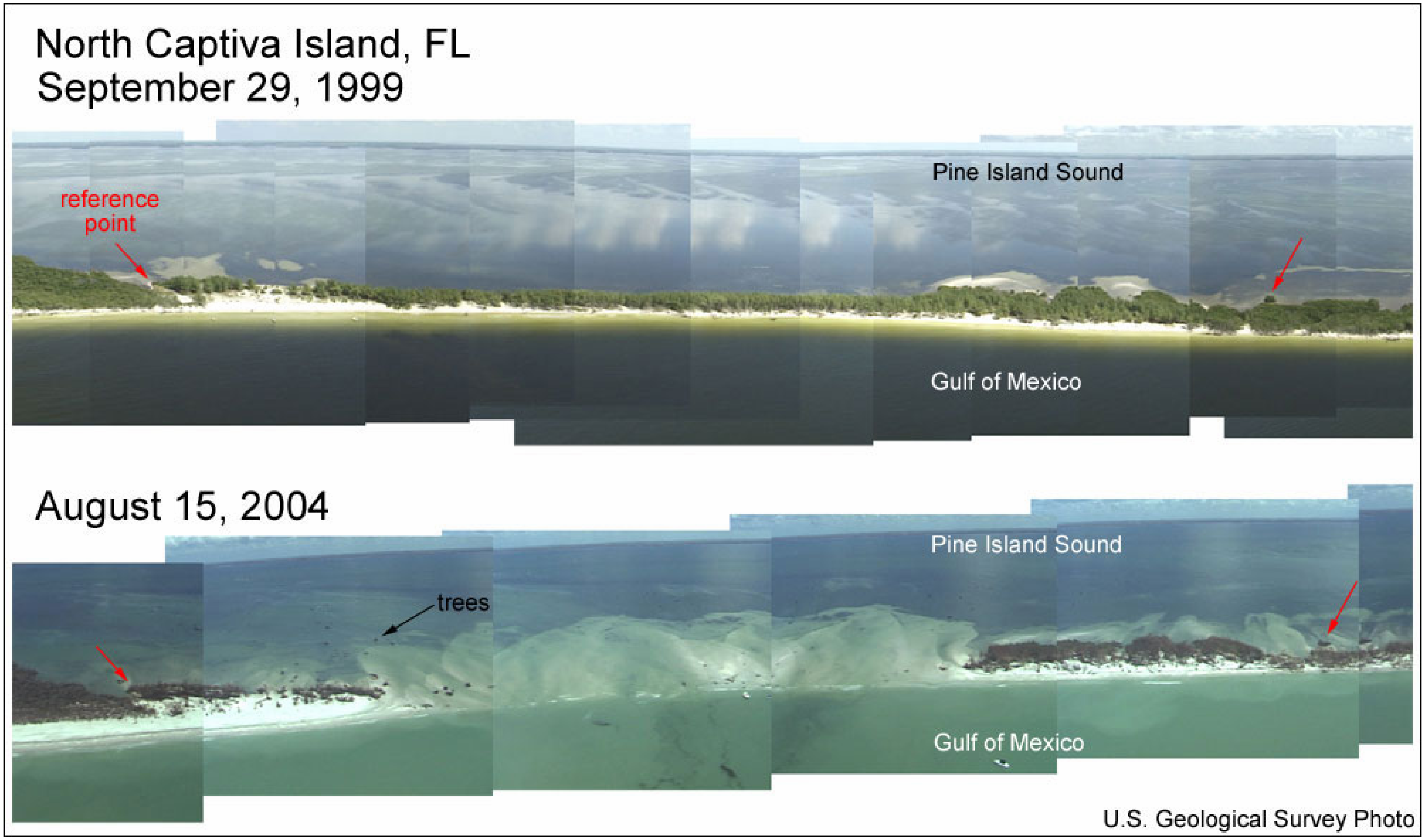

Figure 7. Aerial photograph of the breach at North Captiva Island. Graphic provided by the USGS Coastal & Marine Geology Program, Hurricane and Extreme Storm Impact Studies. Accessed November 2004 <http://coastal.er.usgs.gov/hurricanes/charley/index.html>.

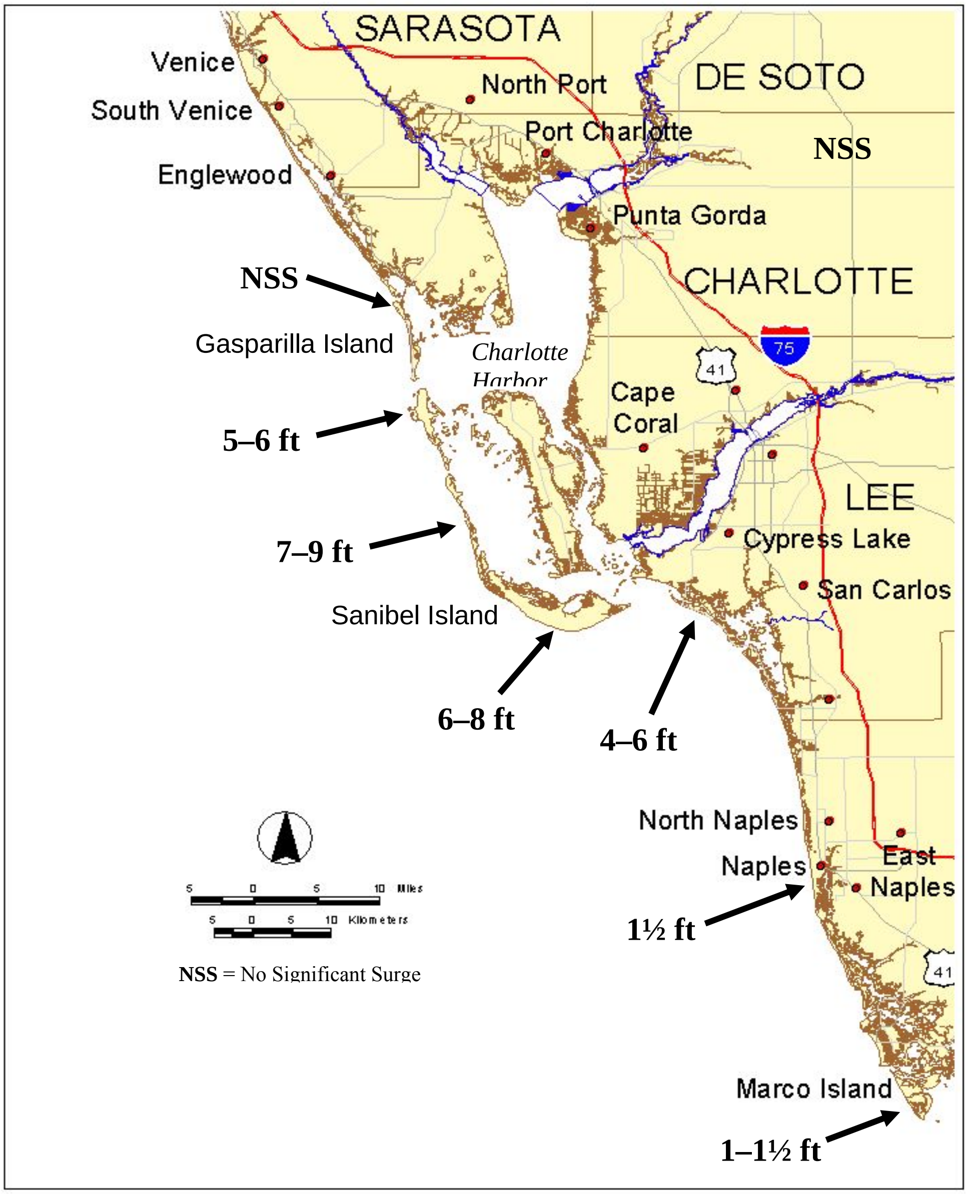

Figure 8. Visually estimated open coastal high water levels during Hurricane Charley (based on unsurveyed estimates subject to change and corrections) August 24, 2004. Data and Figure provided to USGS by the Coastal High Water Study Team under the Federal Emergency Management Agency (FEMA).

NSS = No Significant Surge

Figure 9. Visually estimated open coastal high water levels during Hurricane Charley (based on unsurveyed estimates subject to change and corrections) August 24, 2004. Data and Figure provided to USGS by the Coastal High Water Study Team under the Federal Emergency Management Agency (FEMA).

Figure 10. Moderate damage from Hurricane Charley, 13 August 2004, to mangrove habitat along Wildlife Drive, “Ding” Darling National Wildlife Refuge, Sanibel, Florida, photographed 21 September 2004.

Figure 11. Severe damage from Hurricane Charley, 13 August 2004, to mangrove habitat on the Shell Mound Trail, “Ding” Darling National Wildlife Refuge, Sanibel, Florida, photographed 21 September 2004.

Figure 12. Moderate damage from Hurricane Charley, 13 August 2004, to upland live oak forests near "Legion Curve," "Ding" Darling National Wildlife Refuge, Sanibel, Florida, photographed 22 September 2004.

Figure 13. Seagrass beds at low tide along Wildlife Drive, "Ding" Darling National Wildlife Refuge, Sanibel, Florida, photographed 21 September 2004. Twenty to 30 wading birds were foraging in the area.

Figure 14. Catastrophic damage from Hurricane Charley, 13 August 2004, on the island edge (top) and interior (bottom) of Lumpkin Island, Matlacha Pass National Wildlife Refuge, Lee County, Florida, photographed 23 September 2004.

Figure 15. Moderate damage from Hurricane Charley, 13 August 2004, on Upper Bird Island (top), island edge (middle) and interior (bottom), Matlacha Pass National Wildlife Refuge, Lee County, Florida, photographed 23 September 2004.

Figure 16. Moderate damage from Hurricane Charley, 13 August 2004, on Givney Key: island edge (top) and interior (bottom), Matlacha Pass National Wildlife Refuge, Lee County, Florida, photographed 23 September 2004.

Figure 17. Moderate damage from Hurricane Charley, 13 August 2004, on Lower Bird Island, Matlacha Pass National Wildlife Refuge, Lee County, Florida, photographed 23 September 2004. Loss of leaf cover occurred on about 50% of coverage.

Figure 18. Moderate damage from Hurricane Charley, 13 August 2004, on Lower Bird Island: island edge (top – moderate), island edge (middle – mild), and island interior (bottom), Matlacha Pass National Wildlife Refuge, Lee County, Florida, photographed 23 September 2004.

Figure 19. Catastrophic damage from Hurricane Charley, 13 August 2004, on Bird Key: island edge (top, large snapped black mangrove is sprouting) and island interior (bottom), Pine Island National Wildlife Refuge, Lee County, Florida, photographed 24 September 2004.

Figure 20. Catastrophic damage from Hurricane Charley, 13 August 2004, on Hemp Island, Pine Island National Wildlife Refuge, Lee County, Florida, photographed 24 September 2004. Large numbers of resting waterbirds had been using the island based on white wash and fecal matter on the ground.

Figure 21. Catastrophic damage from Hurricane Charley, 13 August 2004, on Hemp Island: island edge (top), rim (middle) and interior (bottom), Pine Island National Wildlife Refuge, Lee County, Florida, photographed 24 September 2004.

Figure 22. Wood Storks (3 of 11) leaving Hemp Island, Pine Island National Wildlife Refuge, Lee County, Florida, 24 September 2004.

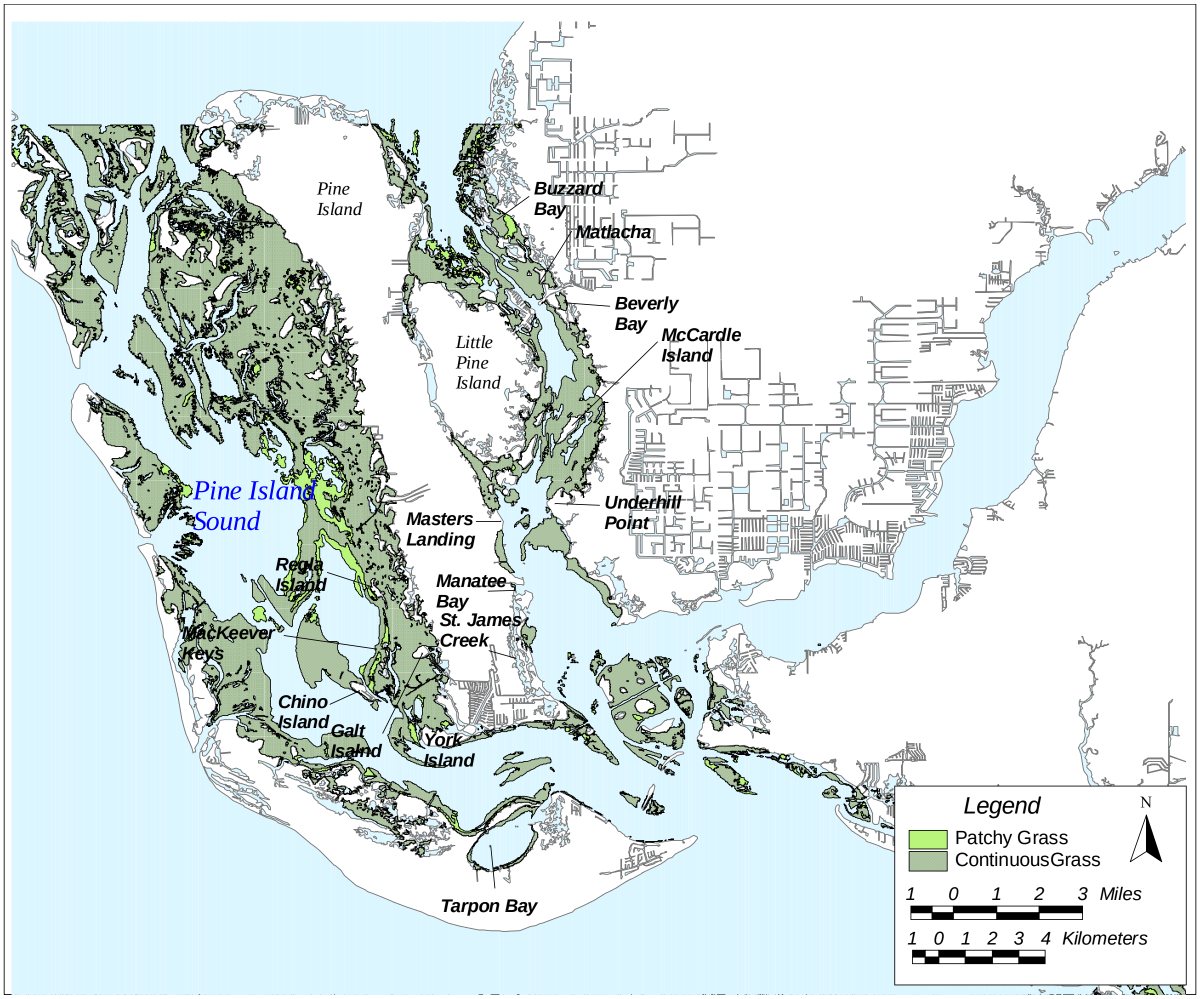

Figure 23. Seagrass coverage of Matlacha Pass and Pine Island Sound, Florida, from 1999. Figure provided by FWRI.

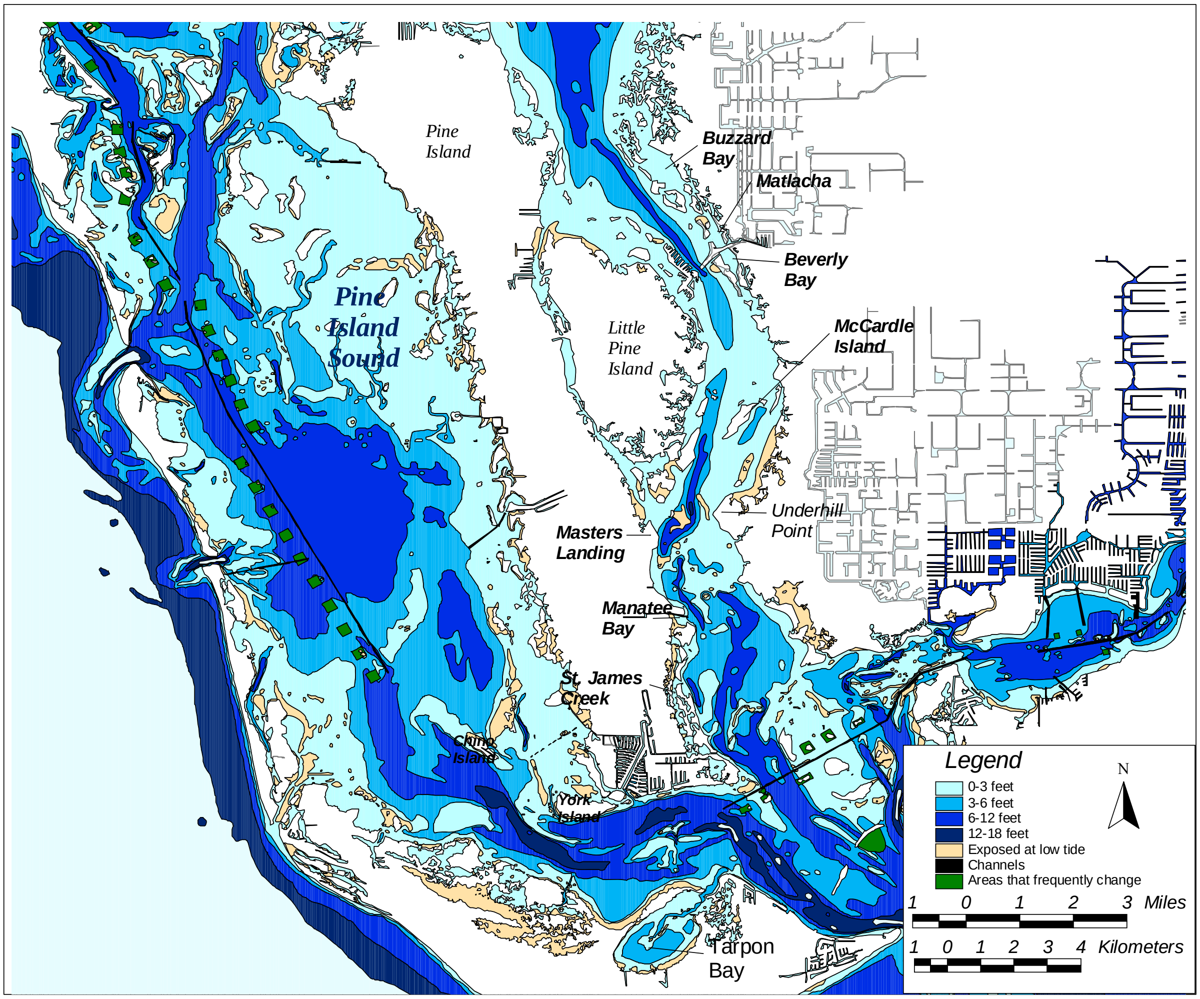

Figure 24. Bathymetry of Matlacha Pass and Pine Island Sound, Florida. Figure provided by FWRI.

Figure 25. Sand inundation of seagrass bed at the breach on North Captiva Island, Florida, and scarring from trees dragged by the storm.

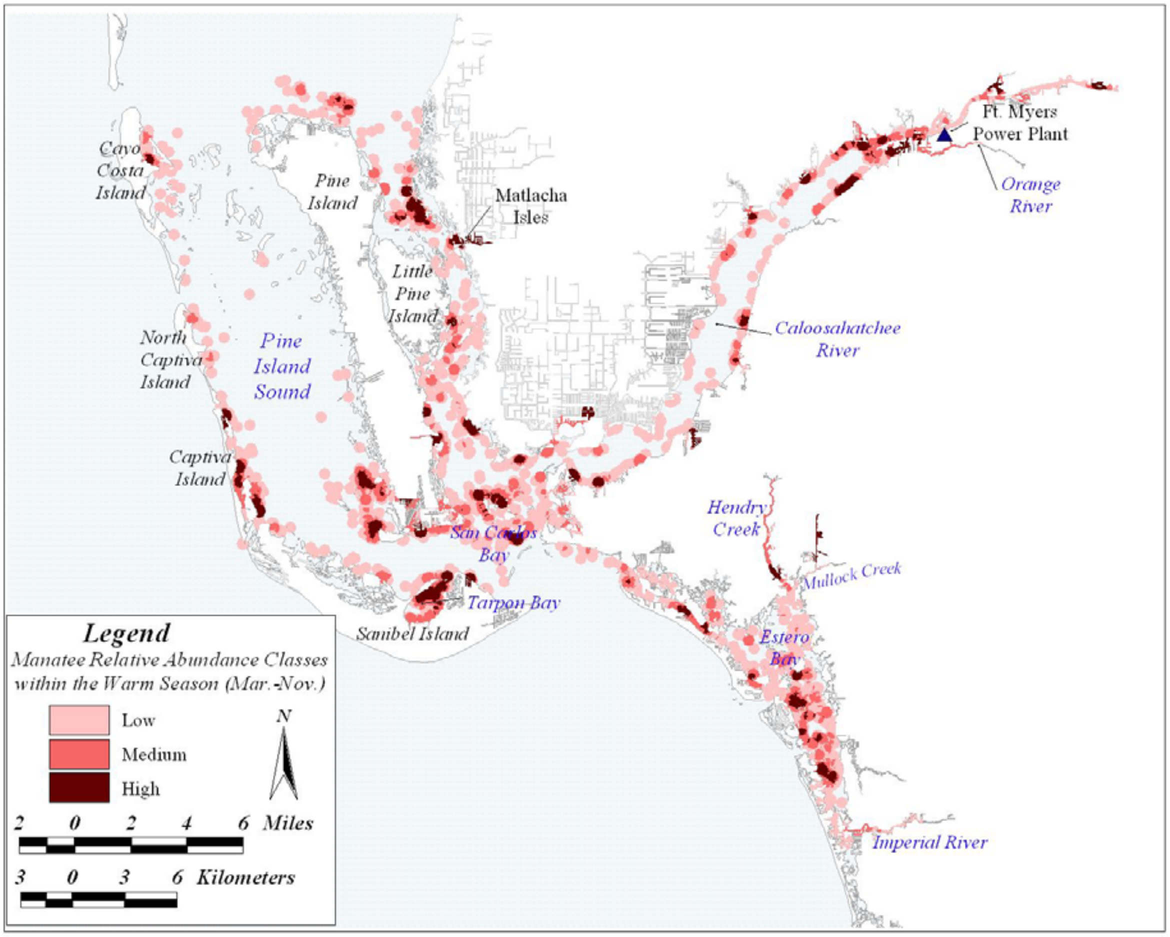

Figure 26. Relative abundance of manatees within the warm season (Mar.-Nov.) based on aerial surveys of Lee County, Florida, conducted 1994-1995 and 1997-1998. Analysis and Figure provided by FWRI.

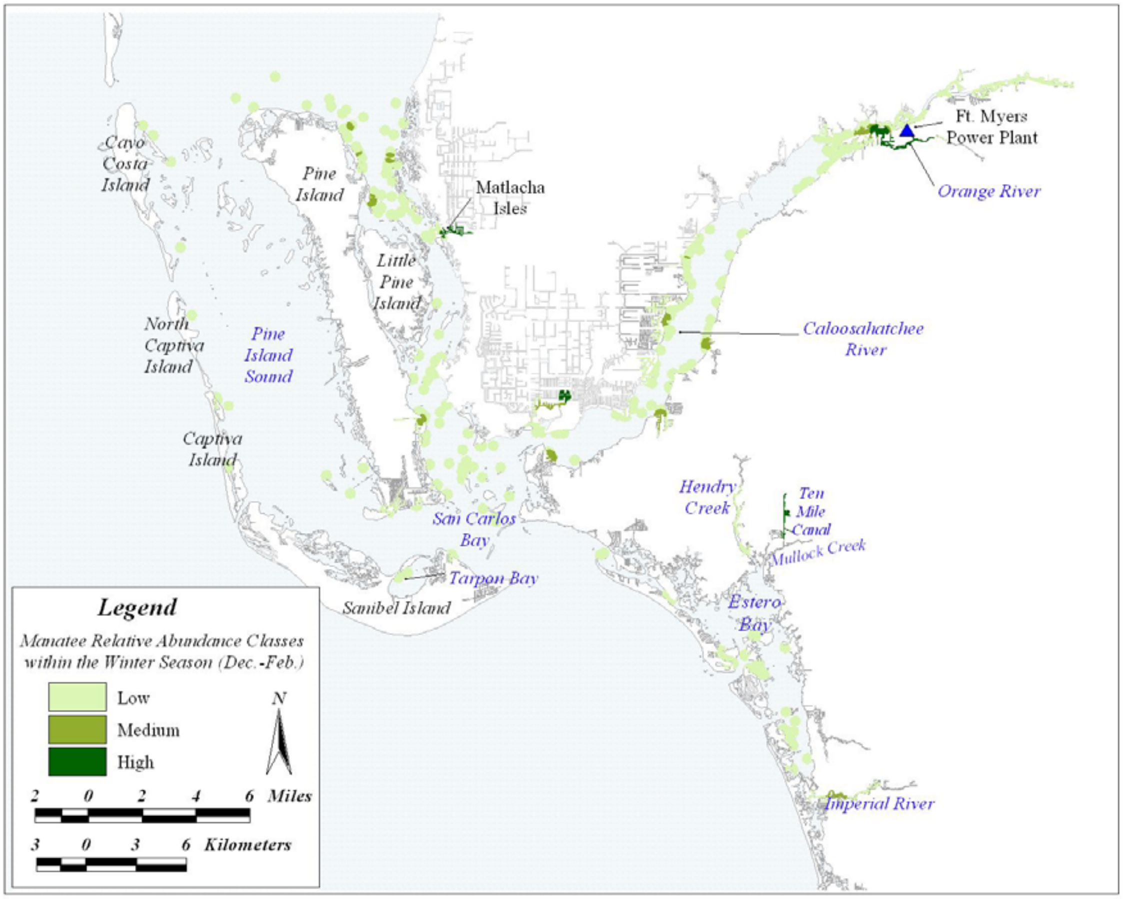

Figure 27. Relative abundance of manatees within the cold season (Dec.-Feb.) based on aerial surveys of Lee County, Florida, conducted 1994-1995 and 1997-1998. Analysis and Figure provided by FWRI.

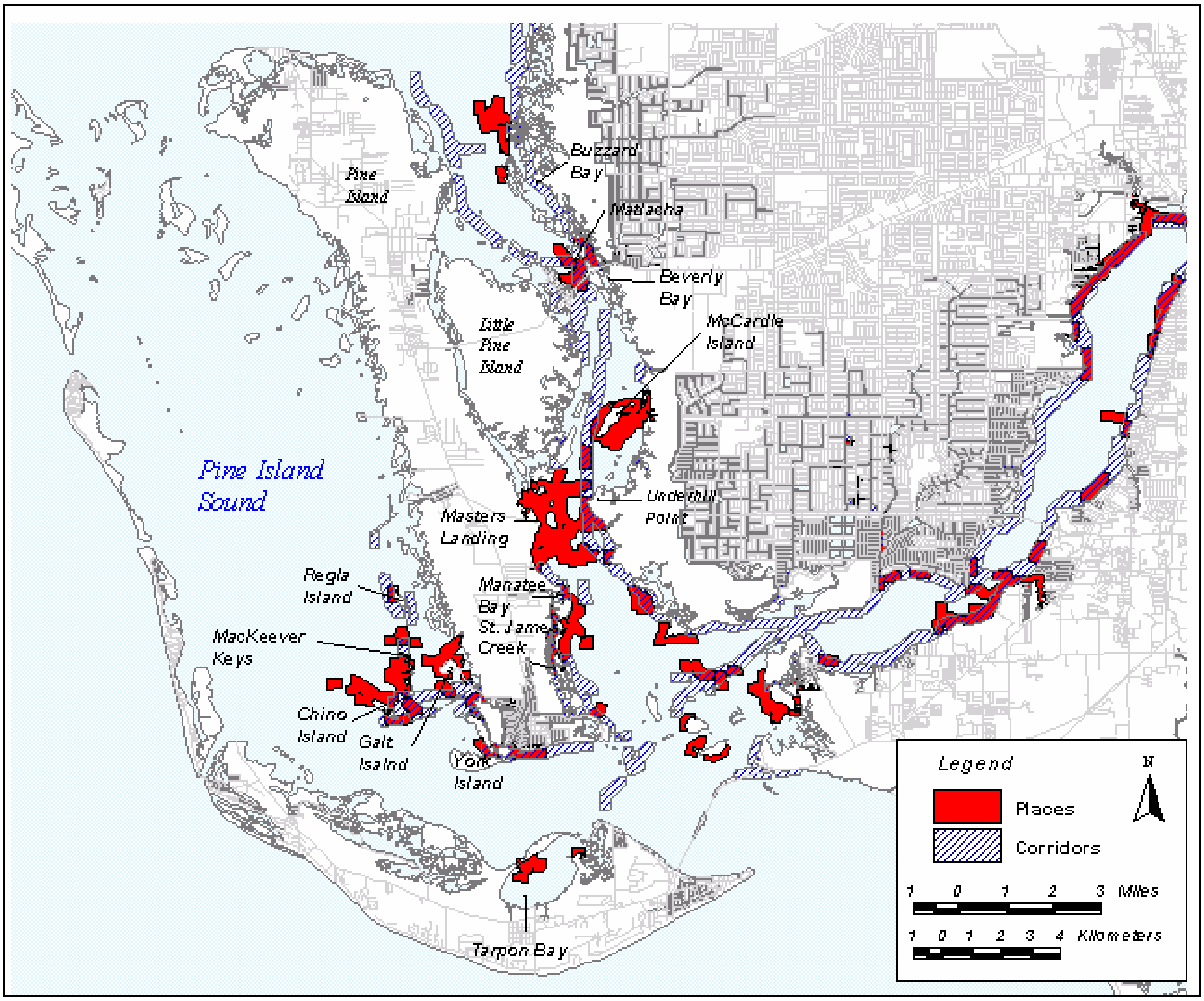

Figure 28. Manatee places and corridors for Matlacha Pass and Pine Island Sound, Florida. Analysis and figure provided by FWRI.

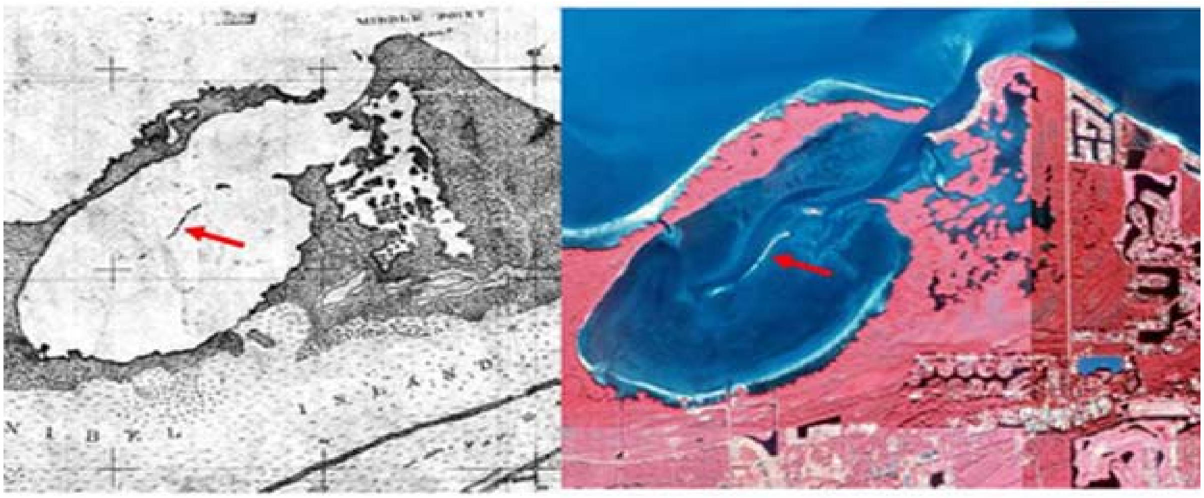

Figure 29. The Tarpon Bay Keys (red arrows), Florida, as depicted on topographic sheet T-693 from 1859 (left) and in a 1999 false color infra-red aerial photograph. The two images are not to equal scales.

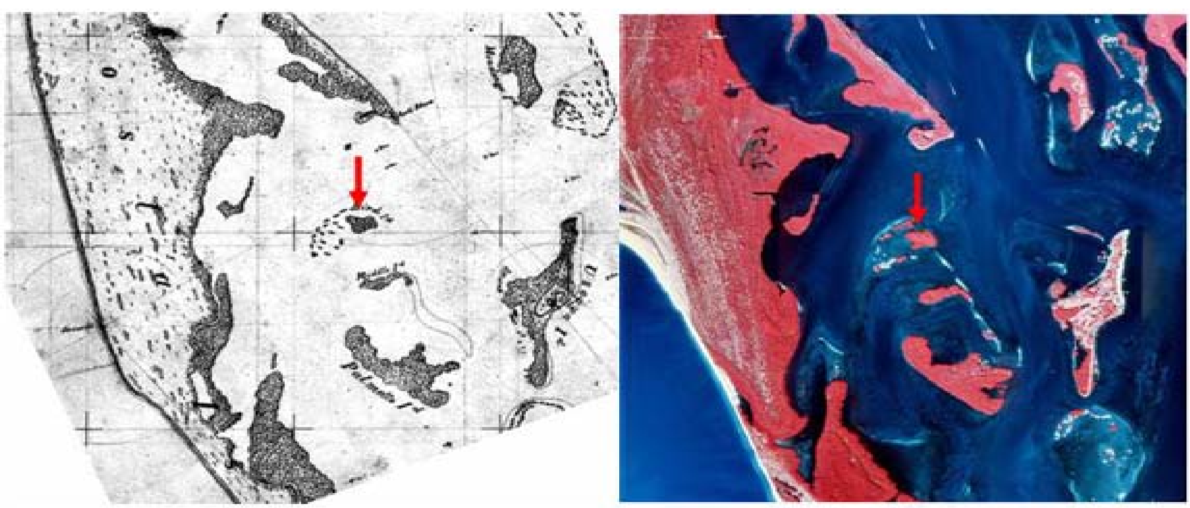

Figure 30. The old and new of northern Pine Island Sound, Florida. Topographic sheet T-738 from 1859 (left) and a false color infra-red aerial photograph from 1999. Bird Key is located near the center of both images (red arrow). The two images are not to equal scale.

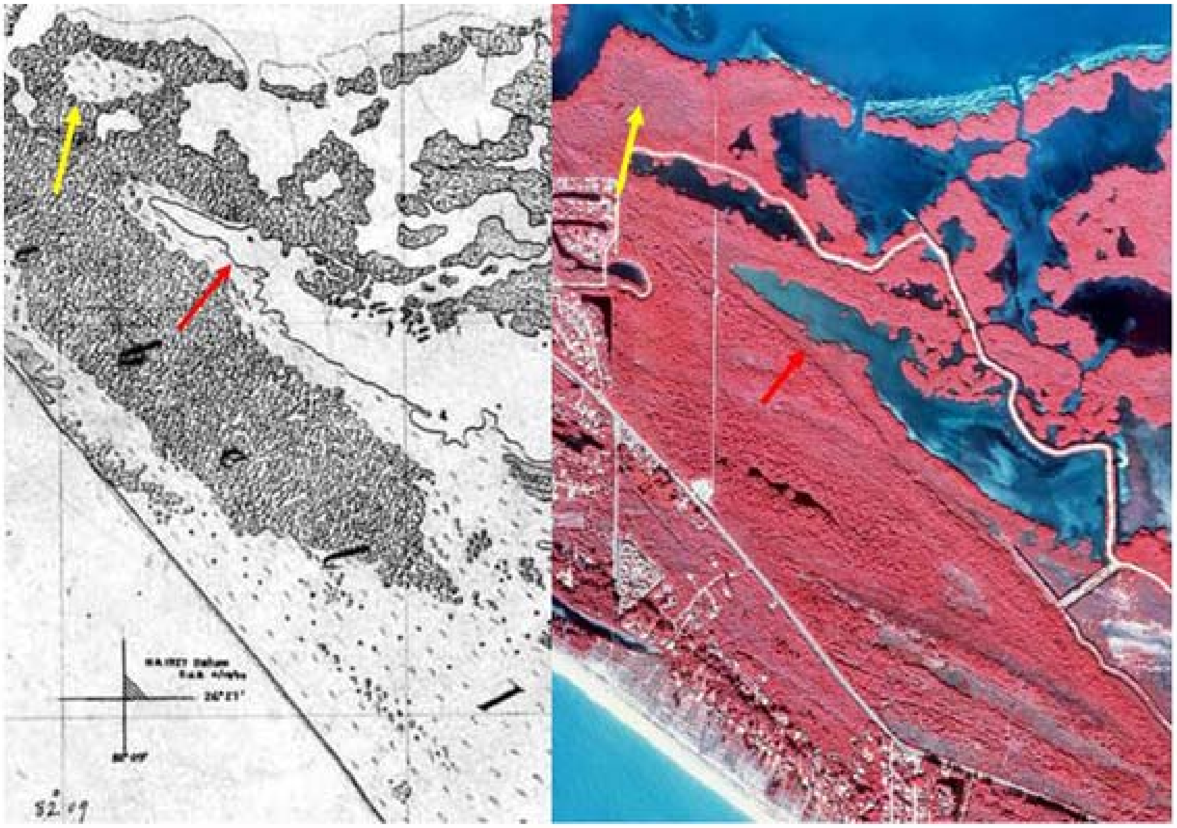

Figure 31. Comparison of the Shell Mound Trail area and West Impoundment area of J. N. “Ding” Darling NWR in 1859 (left) and 1999 (right), Florida. Lack of apparent shoreline change (red arrows) and apparent vegetation change (yellow arrows) are indicated. The two images are not to equal scale.

Figure 32. Evidence of human occupation of Hemp Island, Florida. A tip-up mound and pit reveal the existence of past Calusa habitation in the form of conch, clam, and whelk shells (left). The presence of lily and papaya plants indicate human occupation much after the Calusa habitation (right).

Figure 33. Two views of overwash deposits from Hurricane Charley. On the left is a close-up showing approximately 13 cm of sediment on Upper Bird Island. The right hand panel shows an overwash lobe of about 50 cm depth on Givney Island, Florida.

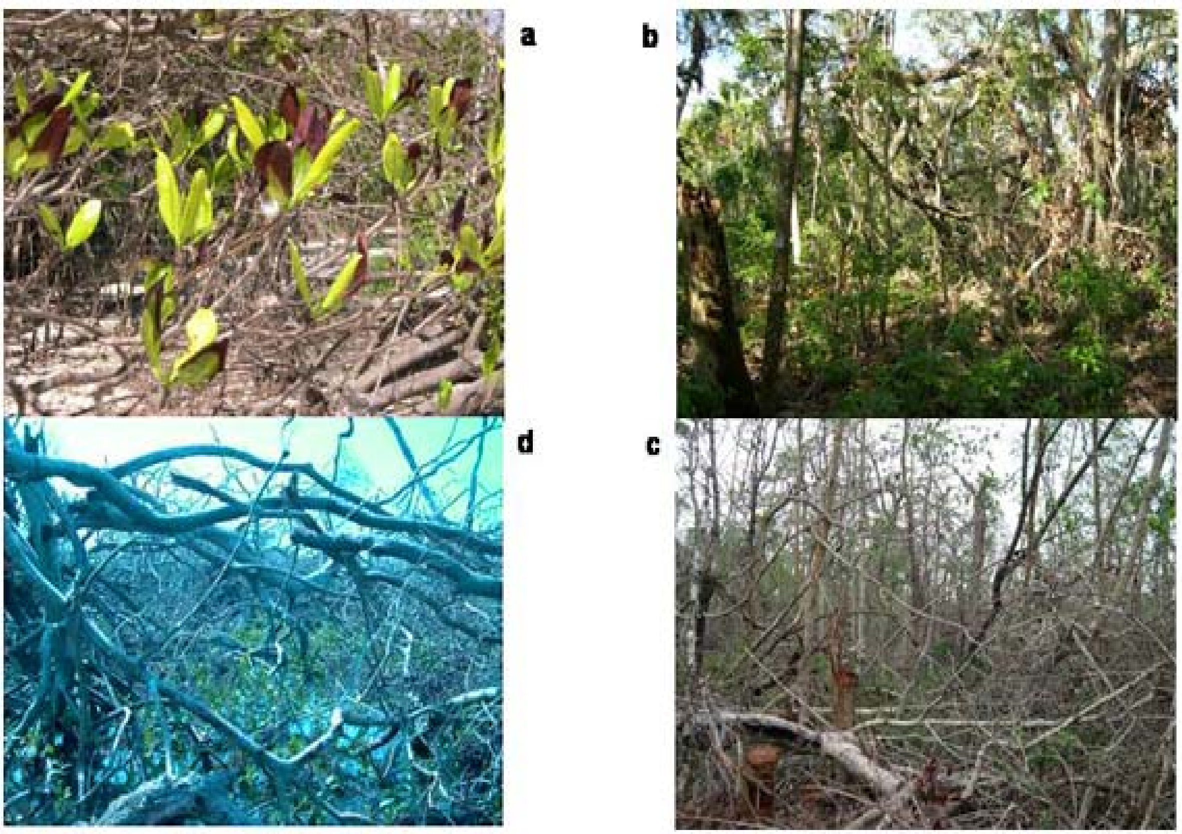

Figure 34. Levels of hurricane damage range from: (a) leaf burn from salt, (b) defoliation and branch loss, (c) some stem blown down, and (d) total canopy loss.

Black mangrove Gumbo limbo Sea grape

Figure 35. The ability to re-sprout following leaf and branch loss varies greatly among species. In general, species with a tropical origin have higher coppicing ability than do temperate species. These photographs were taken five weeks following Hurricane Charley. The red mangrove, a dominant species in the mangrove forests of Florida, lacks coppicing ability.

Figure 36. Advanced regeneration, i.e., the presence of seedlings and saplings (from seed banks) in a forest's understory is important to recovery following disturbance. It is abundant in some locations, such as Bird Key (left), and almost totally absent in other areas, such as Givney Key (right), Florida.

Figure 37. Tip-ups increase sediment micro-topography by creating mounds and pits: (a) live oak on Legion Curve area, (b) black mangrove on Bird Key, and (c) gum limbo on Hemp Island, Florida.

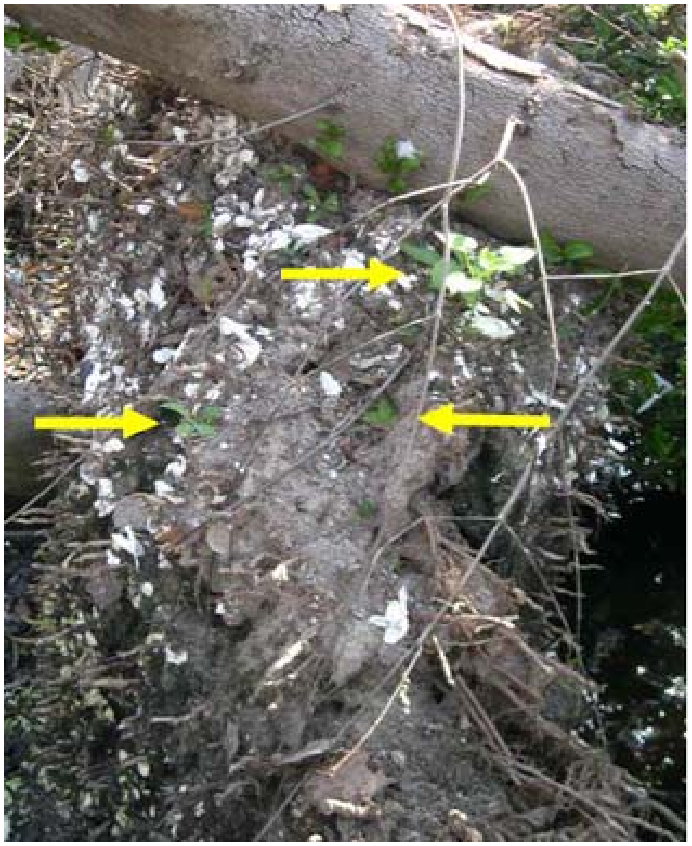

Figure 38. Tip-up mounds also provide places for species to regenerate and colonize. Here, non-mangrove plant species (yellow arrows) colonize a tip-up mound on Givney Key, Florida.

Figure 39. Proliferation of vines is common following disturbance. Nicker bean, a native species, grows on Hemp Island (left), while, air potato, and invasive exotic, spreads rapidly along Shell Mound Trail, Sanibel Island, Florida (right).

Figure 40. Nests of White Ibis (*Eudocimus albus*) in a Brazilian pepper tree on Hemp Island, Florida.

Figure 41. A dune swale freshwater marsh (left) and white-topped sedge (*Rhyncospora latifolia*) growing in the marsh (right, enlargement), Legion Curve area, Sanibel Island, Florida.

Figure 42. Water control structures along Powerline Road, Sanibel, Island, Florida. A structure (left, yellow arrow) on east side of the road that directs surface water from south to north. A partially collapsed culvert (right, yellow arrow) with water flowing from the Shell Mound Trail area to east under Powerline Road.

Figure 43. Sanibel-Captiva Conservaton Foundation mangrove plot 7 located west of Dixie-Beach Boulevard, Sanibel Island, Florida. The yellow arrows point to the pink paint used to mark the border of the plot.

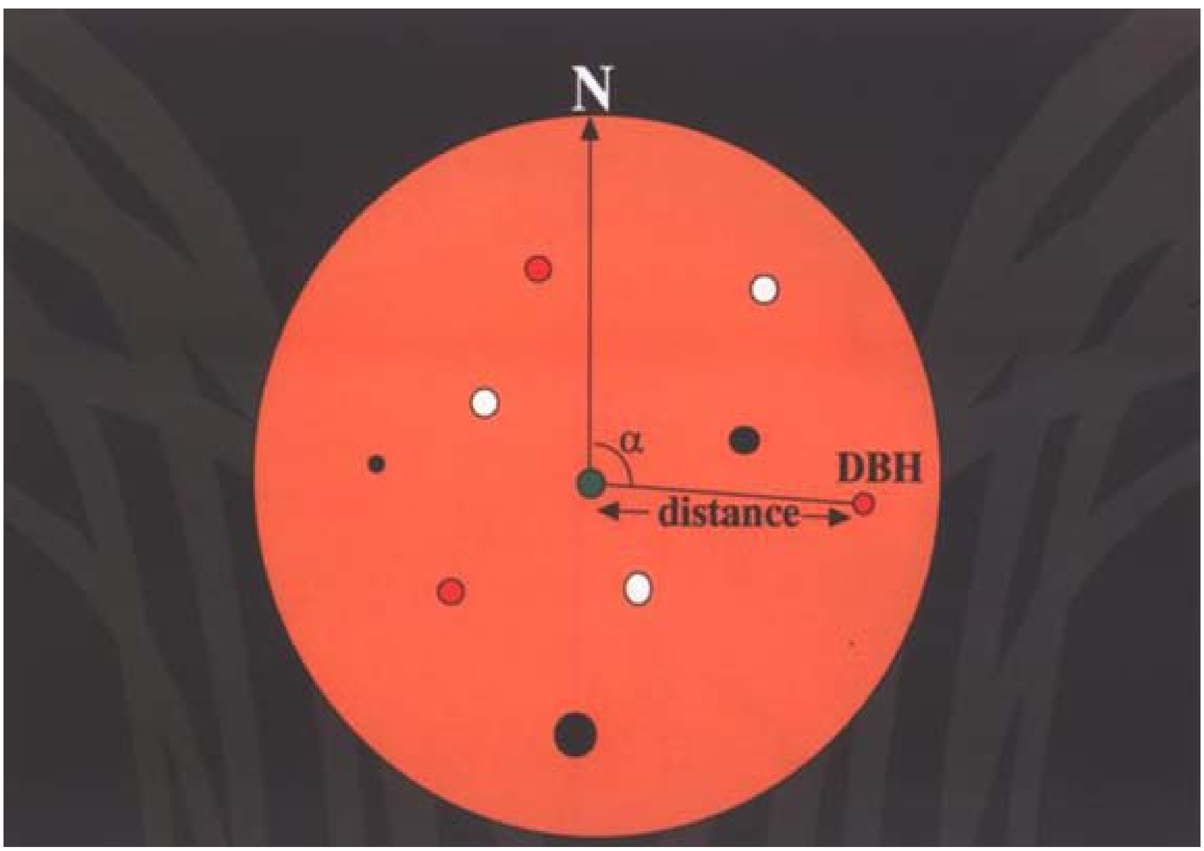

Figure 44. Plot layout (in red) used by USGS for mangrove vegetation studies in coastal Everglades, Florida. From the permanent center stake, the distance and bearing (α) to each stem is recorded as well as the diameter breast height (DBH) and species.